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NO. 1123

## SPADE

### AN INTERACTIVE COMPUTER PROGRAM FOR SIGNAL
### PROCESSING AND DATA ENHANCEMENT OF AIR-BLAST
### STRUCTURAL RESPONSE MEASUREMENTS. (U)

*INTRODUCTION AND USER'S MANUAL (U)*

by

R. Houlston and J.E. Slater

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## ABSTRACT

This report describes the theory and operation of a computer program referred to as SPADE (Signal Processing and Data Enhancement). SPADE is a computer program for the numerical processing of transducer signal data available in the form of digital computer files from air-blast structural response trials. In addition, the program can graphically compare the processed data with predictions made using the finite element structural analysis computer programs VAST and ADINA.

SPADE is a fully interactive program that can be run from a computer terminal. The Tektronix TCS PLOT 10 and AGII packages are used to optionally give an interactive plotting capability. The program has a reasonably comprehensive set of options which makes it easy and convenient to process the voluminous amount of data that can be generated during a shock wave-structure interaction experiment. With reasonable ease the program can be adapted to the processing of any type of transducer output. However, the application of SPADE described in this manual is to the processing of data from pressure transducers, accelerometers, and strain gauges on simple plates and stiffened panels exposed to air-blast shock wave loading.

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## TERMINOLOGY*

ANGLE or ANG    The angle that the centreline of a strain gauge makes with the XC axis (3.3).

C    See Calibration Constant.

CALIBRATE or    The height of the Calibration Pulse in engineering units
CAL    (usually gravities (G) for acceleration, pounds per square inch (PSI) for pressure, and microstrain ($\mu$e) for strain on the Calibration Pulse Data File (CPDF) (5).

CALIBRATION    The equivalent number of engineering units per Volt of output
CONSTANT or C    for a transducer (5.0).

CALIBRATION    The digitized calibration pulse on the Calibration Pulse Data
PULSE or CP    File (6.2.2).

CDS    Computer Group Data Sheet (2).

CG    Computer Group (2).

CHANNEL or CHAN    See Transducer Channel.

CPDF    Calibration Pulse Data File (2).

CPDP    The Calibration Pulse Definition Point(s) (6.2.2).

---

*The section number where first defined is given in brackets.

TERMINOLOGY (cont'd)

DDS          Derived Displacement Signal (6.8.1).

DDSF         Derived Displacement Signal File (6.7).

DIGITIZING   The equivalent real time during recording of a Transducer Signal
START TIME   that digitizing is started. It is specified on the Computer
             Group Data Sheet (CDS) with Y, D, H, M, S, MS, where Y is the
             year (4 digits), D is the day of the year (3 digits), H is the
             hour of the day (2 digits), M is the minutes into the hour (2
             digits), S is the seconds into the minute (2 digits), and MS is
             the number of milliseconds into the second (3 digits) (5).

DRATE        The number of samples per second of recording time extracted
             from the analog tape and converted to integers in the digitizing
             process (4.3).

DRES         Defence Research Establishment Suffield.

DU           Digitized units. The units for the values of the data points on
             the Signal Data File (SDF). This should not be confused with
             the units of measurement (RU) on the Scaled Signal Data File
             (SSDF) (6.1).

DVS          Dervied Velocity Signal (6.8.1).

DVSF         Derived Velocity Signal File (6.6.3).

E            See Signal Scale Factor.

## TERMINOLOGY (cont'd)

EDIG            Electronic Design and Instrumentation Group (2).

EDS             Electronic Design and Instrumentation Group Data Sheet (2).

EVENT           The time of charge detonation (4.3).

FE Transducer   A fictitious transducer (identified with a Channel Number
                greater than 500) which gives a finite element prediction of a
                transducer signal rather than a measured value.

GAIN            A value applied during the digitizing process that determines
                how large an integer that 1 Volt on the analog tape will
                produce. With GAIN = 1, 10 Volts on the analog tape will produc
                2048 exactly. The integer values will then vary linearly with t
                value of GAIN (4.3).

$h$ (DU)        The height of the Calibration Pulse in Digitized Units (6.2.1). e
                                                                              he

IMAX            Specific Impulse at the positive duration from integration of
                experimental data.

IRIG            Inter-Range Instrumentation Group (4.2).

NOISE           A noise level parameter used to locate CPDP and SDP (6.2.3).

$P_1$, $P_2$, $P_3$, $P_4$   The Calibration Pulse Definition Points (CPDP) or the Signal
$P_5$, $P_6$                 Definition Points (SDP) depending upon the context. Their
                             values refer to actual Point Numbers on a file (6.2.2).

## TERMINOLOGY (cont'd)

PANEL              A number assigned to a panel for identification purposes.  For a
                   specific panel this number will be the same for all experiments
                   done on it (3.5).

Point Number       The actual position number of a sample on a file (CPDF, SDF,
or PN or Point     SSDF).  PN 1 is the very first point on the file and the
                   remaining points are numbered consecutively in increments of 1
                   (6.2.2).

RDF                Raw Data Files

RU                 Real Units or engineering units.  On the Computer Group Data
                   Sheet (CDS) pressure is expressed in Pounds per Square Inch,
                   acceleration in Gravities (G), and strain in Microstrain ($\mu e$).
                   The units on the Scaled Signal Data File (SSDF) for pressure and
                   acceleration, however, will be in SI units:  PASCALS for
                   pressure, $m/s^2$ for acceleration.  Strain will still be expressed
                   as $\mu e$ (6.1).

SDF                Signal Data File (2).

SDP                Signal Definition Point(s) (6.3.2).

SERIES             A numerical digit assigned to a collection of similar
                   experiments (3.5).

SHOT               A number assigned to the event of detonation of a single
                   explosive charge or a set of charges detonated simultaneously
                   (3.5).

## TERMINOLOGY (cont'd)

SIGNAL SCALE FACTOR or E
The scale factor that when multiplied by the values in digitized units of the data points on the relevant SDF will convert them to engineering units (which will be PASCALS for pressure, $m/s^2$ for acceleration, and microstrain ($\mu e$) for strain) (6.0).

SSDF
Scaled Signal Data File. The SSDF contains the results of processing of the Signal Data File (SDF) (6.2.1).

STANDOFF
Perpendicular distance between charge and plate (3.1).

SURFACE or SUR
The Surface Identification Code. Set to T or B to indicate the top or bottom surface of a panel, respectively. The top surface is defined to be that surface directly exposed to the blast wave (3.1).

TDF
Transducer Database File (2).

TLF
Transducer List File (2).

TRANSDUCER CHANNEL or CHANNEL or CHAN
A numerical digit associated with a transducer to indicate the Channel of the data acquisition system to which it is connected (Section 3.4).

TRANSDUCER CODE or TCODE
Symbol such as P2 or A10 used to identify a specific transducer (3.2).

TRANSDUCER COORDINATES
The Cartesian coordinates XC, YC for a gauge. For a strain gauge the term also includes ANGLE (3.3).

## TERMINOLOGY (cont'd)

Y/D/HM:S.MS    Collectively taken as the time.  Y is the year (4 digits), D the day of the year (3 digits), H the hour of the day (2 digits), M the minutes into the hour (2 digits), S the seconds into the minute (2 digits), and MS the number of milliseconds into the second (3 digits) (5).

XC, YC    Cartesian coordinates of a gauge (3.3).

## NOMENCLATURE

$a(t)$          True acceleration at time t.

$\tilde{a}(t)$          Measured acceleration at time t.

$b_o$          Decay constant.

$\bar{\bar{C}}_J$          A coefficient in the least squares polynomial expansion of $\bar{\bar{d}}(t)$.

$\bar{\bar{C}}_J^d$          A coefficient in the least squares polynomial expansion of $\bar{\varepsilon}^d(t)$.

$d$          Decay rate.

$\bar{\bar{d}}_N$          The value of $\bar{\bar{d}}(t)$ at the N'th Point Number on the DDSF.

$d(t)$          True displacement at time t.

$\bar{\bar{d}}(t)$          The approximate derived relative displacement at time t from integrating the approximate derived relative velocities at time t.

$h$          Time increment between data points on an SDF or SSDF.

$I_0^t$          An integration operator such that $I_0^t f(t) = \int_0^t f(x)dx$.

$i_s^+$          Positive specific impulse.

## NOMENCLATURE (cont'd)

$i_s^-$     Negative specific impulse.

$N$     The total number of transducers in the TDF (not including FE transducers).

$N_p$     The number of pressure transducers on the top surface of a panel given in the TDF (not including FE transducers).

$P$     Distance measured along the Calibration Pulse Data File (CPDF), the Signal Data File (SDF), or the Scaled Signal Data File (SSDF) assuming that all the points are 1 distance unit apart and that the start of the file is one distance unit to the left of the first point.  P is also used to denote overpressure.

$P^i$     The distance parameter P for an SDF or SSDF containing data for the i'th transducer on the TDF.

$P_o$     Point number corresponding to t = 0.  Occasionally, depending on the context, it is used to denote an arbitrary fixed point number.

$P_o^i$     A specific value of $P^i$ that corresponds to $T_o$.

$P_s^+$     Peak (side on) overpressure.

$P_s^-$     Peak (side on) underpressure.

$P(t^-)$     Overpressure

## NOMENCLATURE (cont'd)

$Q_o$ — Maximum pressure from simple exponential curve fit.

$R$ — Digitizing Rate.

$R^i$ — The digitizing rate for the i'th transducer on the TDF.

$T$ — The IRIG B time.

$T_a$ — Time of arrival of a pressure pulse.

$T_r$ — Rise time

$T^i$ — The IRIG B time associated with a position on the SDF or SSDF for the i'th transducer on the TDF that is a distance $P^i$ from the start of the file.

$T_M$ — Minimum time of start of digitizing of pressure tranducers on the top surface.

$T_o$ — A specific value of IRIG B time that is chosen as the t = 0 point for all transducers on the TDF (except FE transducers).

$T^+$ — Positive phase duration.

$T_s^i$ — The IRIG start time of digitizing for the i'th transducer on the TDF.

$T^-$ — Negative phase duration.

$t_i$ — Time corresponding to the i'th point number on an SSDF.

## NOMENCLATURE (cont'd)

| | |
|---|---|
| $t^-$ | Time measured from the position of maximum pressure. |
| $t$ | Time measured from a chosen point determined by SPADE on the IRIG B time scale. |
| $Y_N$ | Data value of the N'th Point Number on a Calibration Pulse Data File (CPDF) or a Signal Data File (SDF or SSDF). |
| $\bar{Y}_N^M$ | The data value average of points N to M inclusive on a data file (CPDF, SDF, SSDF). It is assumed that M ⩾ N. |
| YMAX, YMIN | Maximum and minimum values of data points. |
| $y(t)$ | True data value on an SSDF corresponding to time t. |
| $\tilde{y}(t)$ | True data value on an SSDF if $t = t_i$ only. For $t \neq t_i$, then an approximate interpolated value. |
| $v(t)$ | True velocity at time t. |
| $\bar{v}(t)$ | The approximate derived relative velocity at time t found from integrating $\tilde{a}(t)$. |
| $Z_N$ | Data value of the N'th Point Number on a Scaled Signal Data File (SSDF). |
| $\Delta B$ | Noise Band. Data values that do not differ by $\Delta B$ are not considered to be significantly different. |
| $\tilde{\varepsilon}^a(t)$ | Measured value of acceleration minus the true value of acceleration at time t. |

## NOMENCLATURE (cont'd)

$\bar{\epsilon}^v(t)$          The correction at time t that must be subtracted off $\bar{v}(t)$ to give $v(t)$.

$\bar{\bar{\epsilon}}^d(t)$          The correction at time t that must be subtracted off $\bar{\bar{d}}(t)$ to give $d(t)$.

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Enhancement of Air-Blast Structural Response Measurements :

*INTRODUCTION AND USER'S MANUAL*

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1. INTRODUCTION

The Defence Research Establishment Suffield (DRES) is currently conducting
research on the effects of air blast waves on warship structures such as
stiffened panels. The work includes extensive testing of both model and full
scale structures. Since these experiments generate voluminous amounts of data,
an efficient data processing procedure is required. This report describes a
computer program SPADE (Signal Processing and Data Enhancement), which has been
developed for the numerical processing of transducer signal data available in the
form of digital computer files from air blast structural response trials. The
program can also process data files created with the finite element computer
programs VAST [1], ADINA [2], or DRESDYN [3], for subsequent plotting with
associated experimental results for data correlation studies. SPADE is fully
interactive and has been written with the intent of making it as easy as possible
to process the voluminous amount of data that can be generated during a shock
wave-structure interaction experiment.

SPADE-PLOT and SPADE-PLOTR [4] are also fully interactive computer programs
for graph plotting of the finite element and/or experimental data files created

with SPADE.  The Calcomp plot routines are used for high quality graphs.  SPADE
also has the option of using the Tektronix PLOT 10 TCS and AGII plotting routines
for interactive graph plotting during data processing if a graphics terminal is
being used.

Background information and the capabilities of SPADE are described fully in
Sections 2 to 6.  The use of the program is then discussed in Section 7.

A series of sample runs which illustrate how to run the programs on a
computer terminal is given in a separate document [5].

## 2.  DATA ACQUISITION

Figure 1 shows a block diagram to illustrate the data acquisition procedure
from an experiment and the processing involved.  The target structure is equipped
with transducers such as pressure gauges, strain gauges, and accelerometers.
Data from these transducers are recorded by the Electronic Design and
Instrumentation Group (EDIG) on magnetic tape in analog form.  In addition, data
for calibration pulses (which will be discussed subsequently) is recorded.  An
EDIG Data Sheet (EDS) is also compiled for recording information relevant to the
data acquisition and analog signal conditioning.  The EDS is discussed in
Appendix A.

On completion of the experiment, the next step is to digitize the analog
signals.  This process is handled by the Computer Group (CG) with information
provided by EDIG on the EDS.  As a result of the digitizing process, a new
magnetic tape is created containing the same data as recorded by EDIG but in
digital form.  Both Calibration Pulse Data Files (CPDF) and Signal Data Files
(SDF) are stored on this tape and are given definite file names (Appendix B2).
Before processing by SPADE can begin, the files required must be extracted from
this tape.  SPADE also produces other files during processing referred to as the
Transducer List File (TLF) and the Transducer Database File (TDF) which will be
discussed in Section 6.1 and Appendix B.

In addition to creating the digitized data files, the Computer Group will also produce a special data sheet referred to as a Computer Group Data Sheet (CDS) to be discussed in Section 5.

3.   PRELIMINARY DEFINITIONS

3.1   Introduction

The structure referred to in Figure 1 could be of any type but the main interest at the time of writing is in simple plates or stiffened panels that are subjected to an air blast shock wave.  In order to define a few terms that will be used in describing the use of SPADE, a schematic illustration of a simple plate exposed to a blast wave and instrumented with transducers is shown in Figure 2.

The charge is suspended above the geometric centre of the plate such that the line joining the centre of the plate and the centre of the charge is perpendicular to the plate surface.  The length of this line is referred to as the STANDOFF.  By definition, the SURFACE of the plate that is exposed to the blast wave is referred to as surface T to denote the top surface.  The bottom surface is denoted as surface B.

3.2   Transducer Codes

In general, several different types of transducer could be used to measure the blast wave characteristics and the associated structural response.  For the plate in Figure 2 only a pressure gauge, an accelerometer and a strain gauge are shown.  There are, in general, several transducers of the same type.  For the purpose of transducer identification, each transducer is given a specific TRANSDUCER CODE of the form XN where X is a single letter to denote the transducer type and N is an integer usually of one or two digits.  For a pressure gauge X is P, for an accelerometer A, and for a strain gauge S.  N will usually be taken as 1 for the first transducer of a particular type and will then be

incremented by 1 for each of the other transducers of this type.  However, N can
be assigned arbitrarily subject to being unique for each transducer of a
particular type.  In Figure 2 the transducer codes are P3, A2, and S15.

## 3.3  Transducer Coordinates

In addition to identifying a particular transducer uniquely with a
transducer code, it is necessary to define the position of that transducer on the
structure.  This is done with the TRANSDUCER COORDINATES.  In general a
rectangular Cartesian coordinate system can be used to define the spatial
position of a point uniquely.  In the case shown in Figure 2, a two dimensional
rectangular Cartesian coordinate system is used with the origin at the
geometrical centre of the plate and the axes passing through the middle of the
plate sides.  Specification of the surface (T or B) and the coordinates (XC, YC)
is sufficient to define the position of a pressure gauge or accelerometer
uniquely.  In the case of a strain gauge an additional coordinate referred to as
ANGLE is required.  This coordinate is the angle that the line along the length
of the gauge makes with the XC axis as shown in Figure 3.  ANGLE is measured
positive as shown (counter-clockwise from the direction of the positive XC axis).
It is sufficient to require $0 <$ ANGLE $< 180°$ since no direction needs to be
associated with the line $\overline{AB}$.  This means that a rotation of the strain gauge by
$180°$ so that A replaces B and B replaced A in Figure 3 does not change the strain
gauge coordinates (XC, YC, ANGLE).

## 3.4  Transducer Channels

Each of the transducers shown in Figure 2 produces an electrical signal of
magnitude proportional to the particular stimulus that it is designed to measure.
In the case of a strain gauge, for example, the change of length as it is
stretched with the structure changes the electrical resistance.  Thus, the
electrical current variation with time in a circuit that contains the strain
gauge is a measure of the stretch of the strain gauge or more precisely of the
strain on the surface to which the gauge is attached.  The electrical signal from
each transducer is transmitted to the electronic data acquisition system along

wires attached to the transducer.  Each wire is referred to as a TRANSDUCER
CHANNEL or simply CHANNEL.  Usually a transducer will only be connected to one
channel but in general several channels could be connected to a single
transducer.  This requirement would hold, for example, if the signal from a
specific transducer was required to be recorded with different signal
conditioning requirements.  Several simultaneous records would then be made for
the same transducer.

Each channel is given a number.  In Figure 2 each transducer has only one
channel.  A2 is connected to channel 7, P3 to channel 3 and S15 to channel 107.
These channel numbers are arbitrary but within the following restriction.  In the
EDIG instrumentation trailer there are two tape recorders which can be either
Honeywell (H-101) and/or Ampex (A-PR2200) as illustrated in Figure 2.  Each
channel going to a Honeywell recorder must be assigned a unique number between 1
and 99.  On the other hand, if an Ampex recorder is used, each channel must be
assigned a unique number from 101 to 199.  This assignment of channel numbers is
related to the file naming convention for Raw Data Files (RDF) discussed in
Appendix B2.

## 3.5  Series, Shot and Panel Numbers

In order to identify a particular experiment, a Series Number (SERIES) and
Shot Number (SHOT) are introduced.  These numbers must identify uniquely an
experiment but can otherwise be arbitrary.  The Series Number will usually be
kept the same for a collection of experiments which only differ, for example, in
the standoff and charge weight.  However, the Series Number would probably be
altered if the test facility or type of structure was changed.  The
classification into Series, however, is essentially done in any way that is
convenient.  Experiments within each Series are then given Shot Numbers, usually
starting at 1 and then being incremented by 1 for each test in the Series.

To account for the possibility of more than one panel being involved in a
given Series and Shot, a Panel Number (PANEL) is introduced.  This number is
assigned to a specific panel to identify it.  It is possible that several shots

could be associated with the same Panel in one or more Series, but the combination (SERIES, SHOT, PANEL) will provide unique identification.


## 4. TRANSDUCER ANALOG SIGNALS

### 4.1 Introduction

As mentioned in Section 2 and illustrated in Figure 1, the transducer analog signals recorded by EDIG must be converted to digital form before numerical processing can begin. The recording and digitizing processes will now be briefly summarized in order to define certain terms that occur on the EDS and CDS. Figure 4 illustrates in graphical form the digitizing process.

### 4.2 Recording of Analog Signals

Each of the Ampex or Honeywell tapes has 14 tracks. Twelve of these tracks can be used to record actual transducer signals as illustrated in Figure 4. Either one transducer signal is recorded on each track or multiplexing is used whereby up to five transducer signals can be recorded on each track. The other two tracks are used generally to store timing and firing reference information.

During an experiment such as that illustrated in Figure 2, the following sequence of events occurs. About ten seconds prior to charge detonation, both tape drives are started for recording analog calibration pulse and transducer signals. Approximately 3 seconds ($\pm100$ ms) prior to the charge detonation, rectangular voltage calibration pulses of known magnitudes (lasting about 1 second) are placed on the tracks of the tape. The magnitudes of these pulses will, in general, be different for each transducer and are preset depending upon the transducer characteristics. Following this calibration signal recording, the signals from the various transducers are then recorded on the same tracks of the magnetic tape as the associated calibration pulses.

At the time of charge detonation, a rectangular voltage pulse recorded on track 13 is started and lasts for approximately 1 second. Due to the time required for the blast wave to reach the transducers from the charge, there will be a delay of a few milliseconds from the start of the Det Zero Pulse on track 13 and the detection of a signal from the transducers.

Track 14 on the analog tape is reserved for the Inter-Range Instrumentation Group (IRIG) signal. The IRIG signal comes from the GOES satellite and allows a real time base to be established for all transducer signals. Usually the B type signal is used which allows the time at any point on the tape to be determined to within 1 ms.

## 4.3 Digitizing the Analog Signals

The digitizing procedure consists of scanning the analog tapes and converting the analog signals to digital form (see Figure 4). As the tape moves past the tape head, samples from a selected track are taken at a known rate. This rate can be pre-selected and is usually specified as the number of points per second. For purposes of reference this will be referred to as DRATE.

From each track on the analog tape, two files will usually be created, one is the Calibration Pulse Data File (the CPDF) and the other is the transducer Signal Data File (the SDF) as indicated in Figure 4. The names given to these files depends upon the experiment identification numbers (SERIES and SHOT), the Channel Number (CHANNEL), whether it is a CPDF or SDF, and the type of tape drive (Honeywell or Ampex) used to record the analog signals. This file naming convention for raw data files is discussed in Appendix B2.

The digitizing process can be summarized in the following series of steps:

1.   Scan the analog tape for the EVENT from the time decoded from the IRIG B signal. The event refers to the known time of charge detonation.

2.  Back up the tape for about 5 seconds and scan for the start of the
    calibration pulse on the track corresponding to the transducer of interest.

3.  Back up the tape again to allow a predetermined amount of lead time.

4.  Start digitizing the calibration pulse into the CPDF at approximately 1666
    points per second (1.666 kHz) and record the real time at the start of
    digitizing as determined from the IRIG B signal (time $t_1$ in Figure 4).

5.  Stop digitizing the calibration pulse when the required number of samples
    have been taken (usually 5000).  Since the calibration pulse widths are
    approximately 1 second (Figure 4), this number of digitized points will give
    approximately 1 second of baseline in front of and behind the calibration
    pulse.

6.  Scan the track on the analog tape for the start of the transducer signal.
    This usually occurs about 2 seconds after the end of the calibration pulse.

7.  Back up the tape to allow a preset amount of lead time.

8.  Start digitizing the transducer signal at DRATE samples per second into the
    SDF and record the real time value which corresponds to the point where
    digitizing is started (time $t_2$ in Figure 4).

9.  Stop digitizing the transducer signal when the required length of signal and
    number of sample points have been digitized.

During the digitizing process, the voltage amplitudes taken from the analog
tape are converted to numbers rounded to the nearest integer value.  The size of
number that a one volt amplitude from the analog tape will give depends upon the
gain setting (GAIN).  If GAIN = 1, then 1 Volt will produce the number 204.8
(although this would be stored as 205).  As the gain is increased, however, this
number will increase in proportion.  Thus, if GAIN = 2, then a 1 Volt analog
sample would produce the number 409.6 (stored as 410).

## 5.   THE COMPUTER GROUP DATA SHEET (CDS)

The CDS contains all relevant information required by SPADE plus some additional information for record purposes.  Table 5.1 shows a sample CDS with information that is used for the sample run to be presented in Reference 5. There is one CDS for each experiment (i.e., Series, Shot and Panel).

The sample CDS indicates that the experiment referred to is SHOT 4 in SERIES 1 which was done on 31 March 1983.  The experiment was for a charge of 113 g suspended 3 m above the target plate (see Figure 2) which is identified as PANEL 2.  The EVENT indicates the date and time of the experiment in the format D/HM:S.MS where D is an integer of 3 digits indicating the day of the year, H is an integer of two digits giving the hour of the day, M is an integer of two digits giving the minutes into the hour, S is an integer of two digits giving the number of seconds into the minute, and MS is an integer of 3 digits giving the number of milliseconds into the second.  The accuracy of the event is given to the nearest millisecond.

The various columns of the CDS in Table 5.1 provide information for each transducer used in the experiment.  Columns 1 and 2 give the Channel Numbers and tranducer Codes, respectively.  Three of these transducers (P3, A2, and S15) are illustrated in Figure 2.  Columns 3, 4, and 5 give the transducer coordinates (XC, YC, ANGLE).  XC and YC are specified in millimetres and ANGLE in degrees. Column 6 gives the surface (T or B).  Columns 7 - 12 give the Digitizing Start Time for the transducer signals (time $t_2$ in Figure 4).  For P1, for example, the start time of digitizing was:  Year (Y) = 1983, Day (D) = 90th, Hour (H) = 14, Minute (M) = 9, Second (S) = 59, Millisecond (MS) = 775.  Column 13 gives the digitizing rate (DRATE) for the SDF and is required by SPADE.  Column 14 gives the value of CALIBRATE.  This is the height in real units of the Calibration Pulse for the transducer [usually pounds per square inch (PSI) for pressure gauges, microstrain ($\mu$e) for strain gauges, and gravities (g) for accelerometers].

SERIES 1   PANEL 2   SHOT 4

CHARGE SIZE = 113g   STANDOFF = 3.05m

DATE = 31 MARCH, 1983

EVENT = 090/1410:00.000

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
|  |  | ←←←COORDINATES→→→→ |  |  |  | ←←DIGITIZING START TIME→→→ |  |  |  |  |  |  |  |  |  |
| CHAN | TCODE | XC(mm) | YC(mm) | ANG(DEG) | SUR | Y | D | H | M | S | MS | DRATE(HZ) | CALIB. | GAIN | CAL. CONST REMARKS |
| 1 | P1 | 51 | 560 | NA | T | 1983 | 90 | 14 | 9 | 59 | 775 | 50 000 | NONE | 1 | 10 PSI/V |
| 2 | P2 | 560 | -51 | = | = | = | = | = | = | = | = | = | = | = | " |
| 3 | P3 | -51 | -560 | = | = | = | = | = | = | = | = | = | = | = | " |
| 4 | P4 | 191 | 51 | = | B | = | = | = | = | = | = | 25 000 | = | = | 2 PSI/V |
| 7 | A2 | 0 | 0 | = | = | = | = | = | = | = | = | 50 000 | 640G | = | 8 000 G/V |
| 107 | S15 | -122 | 0 | 0 | = | 1983 | 90 | 14 | 9 | 59 | 750 | 25 000 | 116µε | = | 200 µε/V |

Figure 5.1

A SAMPLE COMPUTER GROUP DATA SHEET

Columns 15 and 16 in Table 5.1 give the GAIN and the Gauge Calibration Constants, respectively. These quantities are only required by SPADE in the exceptional case that a CPDF does not exist.


6.    "SPADE" PROCESSING

6.0  Introduction

In Figure 1, the purpose of SPADE in the processing of digitized transducer signals is summarized. Before processing can begin, the required CPDF and SDF must be available on computer disc files. In addition, all information on the CDS must be available.

There are a total of 12 options available in SPADE. Within restrictions that will be pointed out in subsequent discussions in this section, all options can be executed independently. Also, the execution of the required options can be done in a single run of SPADE or spread over several runs. The program is fully interactive and has been designed to be as simple and convenient to use as possible. The program also has a comprehensive set of error diagnostics.

In the following subsections, an overview of the various options will be given together with any required theory. The actual use of the program is discussed more fully in Section 7, and a large selection of sample runs is presented in Reference 5.

SPADE is executed on the Honeywell DPS 8/70 by giving the CP6 command

!SPADE.A

where A is the account number containing the program. SPADE will then request certain information including the SERIES, SHOT, and PANEL to identify the experiment. In addition, a list of 12 possible options will appear. These options are:

| Option | Description |
|--------|-------------|
| 1 | Set up the TLF and the TDF for a new SHOT. |
| 2 | Determine the SIGNAL SCALE FACTOR from a CPDF. |
| 3 | Scale the transducer SIGNAL DATA FILE. |
| 4 | Define t = 0 from pressure signals. |
| 5 | Determine pressure pulse characteristics. |
| 6 | Integrate acceleration to obtain relative velocity. |
| 7 | Integrate velocity to obtain relative displacement. |
| 8 | Obtain acceleration, velocity, and displacement based on fit to displacement. |
| 9 | FFT and/or filtering of a transducer signal. |
| 10 | Create averaged pressure file and VAST load file. |
| 11 | Extract displacement, velocity, acceleration from VAST file for plotting. |
| 12 | Horizontal or vertical shift with optional rescaling. |

Before discussing each of these options in detail, the Transducer
List File (TLF) and the Transducer Database File (TDF) will be discussed briefly.
The format and names of these files are given in Appendix B.

The TLF is used for listing purposes only and contains the Channel,
Transducer Code, Transducer Coordinates, and the Surface Identification Code
(SUR) from columns 1 to 6 of the CDS as defined in Sections 3 and 5. The TDF
also contains these quantities as well as the Digitizing Start Date/Time, DRATE
and CALIBRATE from columns 7 to 14 of the CDS (see Section 5). Thus all
quantities that are given on the CDS (except the GAIN and Calibration Constant in
columns 15 and 16) are stored on the TDF during execution of Option 1. If the
CPDF does not exist, the GAIN and Calibration Constant are input during Option 1
and immediately converted to the scale factor (E) to be used to scale the SDF to
engineering units. E is then stored on the TDF.

In addition to the CDS data values (which are known before the start of any
SPADE processing) there are certain quantities which are required to be known but

are only determined after certain options have been completed.  These additional
quantities are listed in Table 6.1 together with the option number in which they
are determined.  They will be described in the following sub-sections.

## Table 6.1

Additional Quantities on the TDF Determined by Various Options.

| Quantity | Option |
|---|---|
| Scale Factor E. | 2 (If CPDF exists) <br> 1 (If CPDF does not exist). |
| Calibration Pulse Definition Points $P_1$ to $P_6$. | 2 |
| Signal Definition Points $P_1$ to $P_6$. | 3, 5, 8 |
| Point Number on the SDF for t = 0 (Po). | 4 |
| Decay Constant ($b_0$) and maximum pressure ($Q_0$) for Pressure Tranducer Signals from a simple exponential curve fit. | 5 |
| Maximum Impulse (IMAX) for a Pressure Transducer Signal from integration of experimental data. | 5 |

## 6.1  Option 1:  Set Up Transducer Database Files for a New Shot

This option must be executed before any other processing by SPADE can commence.  The main purpose is to create the TLF and TDF files for the experiment under consideration.  Once these files have been created, the CDS will no longer be required.  All information that the program requires for further options for the particular experiment is stored on the TDF.  As other options are executed this file will be updated.  Appendix B, Table B4.1, contains a description of the format of this file.  Quantities in Table 6.1 that are updated by other options are written as zero to the TDF by Option 1 (with the exception of E when a CPDF does not exist as noted in Table 6.1).  Option 1 will request the following data for each transducer:  CHANNEL, TCODE, XC, YC, ANGLE (if applicable), SUR, Y, D, H, M, S, MS, and DRATE defined in columns 1 to 13, respectively, of the CDS (see "Terminology" at the start of this manual for a review of the meaning of these terms).  The remaining quantities that Option 1 will request are given in columns 14 to 16.  There are two possibilities here depending upon whether the CPDF exists.  Usually it will exist but if SPADE is unable to locate it in the directory specified, the user will be asked to specify whether it exists anywhere.  The information requested by SPADE will then depend upon whether or not it exists and can be accessed.

If the CPDF exists, only the quantity Calibrate from Column 14 will be requested.  Nothing from Column 15 or 16 will be required.  The Calibrate value and the information on the CPDF will then allow Option 2 (to be discussed in the next subsection) to determine the Scale Factor (E) required to convert the SDF to real units (RU).

If the CPDF does not exist, sufficient information must be given to the program to enable E to be determined directly during execution of Option 1. This is done by supplying the GAIN and Calibration Constant (C) from columns 15 and 16, respectively.  How E is obtained from these values will now be explained.

As discussed in Section 4.3, one volt on the analog tape will produce 204.8 x GAIN digitized units (DU) on the CPDF (see Figure 4). The Calibration Constant C, however, is the number of real units of stimulus that must be applied to a gauge to give one volt of output. For a strain gauge, C could be expressed as microstrain per volt and for a pressure gauge as PSI per volt. Thus for 1 volt, C real units (RU) will give 204.8 x GAIN DU's. The Scale Factor E is the number of RU's per DU and hence

$$E = \frac{C}{204.8 \times GAIN} \qquad (6.1.1)$$

Specification of GAIN and C from columns 15 and 16, respectively, thus allows E to be determined directly by SPADE during this option. E is then stored on the TDF.

The final point that is worth mentioning with Option 1 is the flexibility that is allowed in the building of the TLF and TDF. In practice there could be several hundred transducers each of which will require data to be entered from the CDS. For this reason, special features have been built into the program for the user's convenience. These features are:

a)  Corresponding identical entries need not be repeated. Only the terminal return key needs to be depressed.

b)  On completion of entering the data for a transducer, the program can be terminated. When the user decides to carry on, the building of TLF and TDF can continue from the point of termination.

c)  If the same structure and transducers are to be used in several experiments, the TLF and TDF do not have to be created in full for each experiment. Once created for the first experiment, new TLF and TDF can be created for subsequent experiments using information in the previous TLF and TDF. Entries are still required for each transducer, but quantities such as the transducer coordinates are not required to be re-specified. The restart option described in b) also applies in this case.

The use of Option 1 is fully demonstrated in a sample run in Reference 5.

## 6.2  Option 2:  Determine the Signal Scale Factor from a Transducer Calibration Pulse

### 6.2.1  Introduction

The main objective of Option 2 is to determine the Signal Scale Factor (E) required by Option 3 to convert the data on the SDF to real units.  As mentioned in Section 4.2 and illustrated in Figure 4, a rectangular voltage pulse of known magnitude is placed on the analog tape track for each transducer.  There are a certain number of real units of actual stimulus that the gauge must experience to generate this voltage.  This number of real units is derived from the manufacturer's calibration data for the gauge and is stored in column 14 of the CDS.  This quantity will be referred to as CAL.

Once the calibration pulse has been digitized as discussed in Section 4.3, the calibration pulse will have a certain height in digitized units, $\bar{h}(DU)$, as shown in Figure 4.  $\bar{h}(DU)$ is equivalent to CAL real units.  Hence,

$$E = \frac{CAL}{\bar{h}(DU)} \qquad (6.2.1.1)$$

is the SDF scale factor (the number of real units RU per digitized unit DU). Since the same recording and digitizing procedure is used for the transducer signal on the same track as the calibration pulse, it follows that E can be used to convert the digitized transducer signal data on the SDF to real units.  The result of this conversion will be stored on a file referred to as the Scaled Signal Data File (SSDF).  The file naming convention for these files is presented in Appendix B2.

The main objective of Option 2 is thus to calculate $\bar{h}(DU)$ from the CPDF for a transducer.  This value can then be used to calculate E which in turn is used by Option 3 to convert the data on the associated SDF to real units with

background correction.  The results of processing with Option 3 are then stored
on the SSDF.

In the rare case in which the CPDF does not exist, E will have been
determined in Option 1.  Executing Option 2 in this case will result in an echo
of the value of E stored on the TDF.  The sample run in Section 2.2 of
Reference 5 gives a full illustration of the use of Option 2.  Sections 6.2.2 to
6.2.4 below give the details involved in the calculation of $\bar{h}(DU)$.

### 6.2.2  Definition of the Calibration Pulse Definition Points

Figure 5 shows a schematic illustration of a digitized calibration pulse
where the digitized points have been joined by straight lines.  Typically the
total number of digitized points on the CPDF is 5000.  For the purposes of
reference, SPADE uses a set of six Calibration Pulse Defintion Points (CPDP)
denoted as $P_1$, $P_2$, $P_3$, $P_4$, $P_5$ and $P_6$.  These points will now be defined.

Let it be understood that by Point Number (PN) we mean the actual position
number of a point on a digitized file.  Thus PN 1 (or simply point 1) is the
first point on the file.  Similarly, if there are 5000 points on file, PN 5000
will be the last point.  $P_1$ to $P_6$ will each have a value equal to a particular
Point Number.

Points $P_1$ to $P_2$, inclusive, will be defined by SPADE as a set of points
before the Calibration Pulse (CP) that are to be used for background correction.
A set of such points joined by straight lines is illustrated in Figure 5.
Usually $P_1$ will be set to 1 to denote the first point on the file.  Point $P_2$ must
define the start of the pulse rise as closely as possible.  It should not
identify a point on the pulse rise such as X in Figure 5.

Points $P_3$ to $P_4$, inclusive, will be defined by SPADE as the set of points on
the calibration pulse top.  $P_3$ should identify the end of the pulse rise and
again should not be assigned to a point such as X which is on the pulse rise.  $P_3$
will usually turn out to be just 1 greater than $P_2$ since the rise time will

usually be less than the time difference between two consecutive points given by the reciprocal of the digitizing rate.  Point $P_4$ should define the start of the pulse drop.

Points $P_5$ to $P_6$ inclusive will be defined by SPADE as a set of points after the calibration pulse that are to be used for background correction.  Usually $P_6$ will be set to the last point on the file.  Point $P_5$ must define the end of the pulse drop as close as possible.  $P_5$ will also usually turn out to be 1 greater than $P_4$.

## 6.2.3  Determination of the Calibration Pulse Definition Points

SPADE will automatically set $P_1$ to the first point on file and $P_6$ to the last and scan the CPDF for $P_2$ to $P_5$ .  The method used to determine $P_2$ to $P_5$ will now be described.

Let YMAX be the maximum value recorded on the CPDF and YMIN the minimum. Let a parameter NOISE be defined as the background to signal ratio in percent. Then the noise band $\Delta B$ is defined as

$$\Delta B = (NOISE/100) \times \left| (YMAX - YMIN) \right| \qquad (6.2.3.1)$$

Let $Y_N$ and $Y_M$ be the data values of the N'th and M'th points on the CPDF. Then $Y_N$ and $Y_M$ are not considered to be significantly different if the following condition holds.

$$\left| Y_N - Y_M \right| \leq \Delta B \qquad (6.2.3.2)$$

Equation (6.2.3.2) just states that if two data points do not differ in value by at least the noise band then the difference is not considered to be significant.

Point $P_2$ is determined by scanning the CPDF from point 1.  After each point N with data value $Y_N$ is read, it is compared with the baseline average $\overline{Y}\,{}_1^{N-1}$ of

the $Y_I$ values for points I = 1 to N - 1. Since $\overline{Y}_1^{N-1}$ will be approximately the mean line through the noise band, if

$$\left| Y_N - \overline{Y}_1^{N-1} \right| \leqslant \frac{\Delta B}{2} \qquad\qquad (6.2.3.3)$$

then point N is considered to be in the background to the left of the calibration pulse. Otherwise the amplitude of point N is considered to be significantly different than $\overline{Y}_1^{N-1}$. Suppose $Y_N$ is significantly different. In this case is it actually on the pulse rise or is it on just an extraneous spike in the data? SPADE checks this by requiring that the next 9 points also be significantly above the average $\overline{Y}_1^{N-1}$. If this auxiliary condition is not satisfied then point N is not considered to be on the pulse rise and the scan for the pulse rise is continued. If the auxiliary condition is satisfied then point N is considered to be the first point on the pulse rise. $P_2$ is then set to N - 1.

Once $P_2$ has been determined the next step is to find $P_3$, the point number for the start of the pulse top. This is done by reading points $P_2+1$, $P_2+2$, ... from the CPDF and checking whether the point $P_2+I$ currently read is significantly different from the preceding point read. Thus SPADE increments the value of I until the condition

$$\left| Y_{P_2+I} - Y_{P_2+I-1} \right| \leqslant \Delta B \qquad\qquad (6.2.3.4)$$

occurs. Point $P_2+I-1$ is then possibly the first point on the pulse top. To check this the values of the next 9 points must also not differ from each other by more than $\Delta B$. Thus if the condition

$$\left| Y_{P_2+I+J} - Y_{P_2+I+J-1} \right| \leqslant \Delta B \qquad\qquad (6.2.3.5)$$

holds for J = 1 to 9, then $P_3$ is set to $P_2+I-1$.

Point $P_4$ is determined in exactly the same way as point $P_2$. The top of the pulse is scanned from point $P_3$ and a running average is kept. If

$$\left| Y_{P_3+I} - \overline{Y}_{P_3}^{\,P_3+I-1} \right| > \frac{\Delta B}{2} \tag{6.2.3.6}$$

then point $P_3+I$ is possibly a point <u>on</u> the pulse drop. The next 9 points $P_3+I+1$ to $P_3+I+9$ must also differ from $\overline{Y}_{P_3}^{\,P_3+I-1}$ by at least $\Delta B/2$ according to the condition (6.2.3.6). If the next 9 points do satisfy this condition, $P_4$ is set to $P_3+I-1$. $P_4$ is then the highest numbered point on the pulse top that is not on the pulse drop. However, if any of the 9 points do not satisfy this condition, the search for $P_4$ is continued.

Point $P_5$ is determined in a similar way to $P_3$. Thus SPADE increments the value of I from 1 until the condition

$$\left| Y_{P_4+I} - Y_{P_4+I-1} \right| < \Delta B \tag{6.2.3.7}$$

occurs. Point $P_4+I-1$ is then possibly the first point <u>on</u> the background to the right of the calibration pulse. To check this, the values of the next 9 points must also not differ from each other by more than $\Delta B$. Thus if the condition

$$\left| Y_{P_4+I+J} - Y_{P_4+I+J-1} \right| < \Delta B \tag{6.2.3.8}$$

holds for J = 1 to 9 then $P_5$ is set to $P_4+I-1$.

In certain cases, which should rarely occur, the start or the end of the calibration pulse may be missing. SPADE automatically checks for these

conditions.  If the start or the end is missing, $P_2$ or $P_6$ is set to zero, respectively, to indicate this condition.

SPADE gives the user the opportunity to re-scan the CPDF several times with different values of NOISE.  The first scan is done automatically, however, with NOISE = 10%.  The pulse definition points found are then printed.  As illustrated in the sample run in Section 2.2 of Reference 5, several scans of the data file should be made with different values of NOISE (for example, 20% and 30% in addition to the one done automatically with 10%).  The consistency of the results should then be checked.  Usually specifying higher values of NOISE is better than values less than 10%.

When reasonably consistent results are obtained, the user should then check that the pulse definition points found are correct.  This can be done either with interactive graphics (if a graphics terminal is being used) or with a special listing routine in SPADE that allows a direct examination of the data values on the CPDF.  In both cases the pulse definition points can be changed if required. If interactive graphics are used, the pulse definition points can be changed with the graphics cursor.

## 6.2.4  Determination of the Calibration Pulse Height

With the pulse definition points defined on the TDF the next step is to calculate the height of the calibration pulse in digitized units, $\hbar(DU)$, as indicated in Figure 5.  This must be done in an accurate way that allows for baseline drift and superimposed noise in each of the regions defined by the pulse definition points:  Let $P_1$ to $P_2$ inclusive define Region 1, $P_3$ to $P_4$ inclusive Region 2, and $P_5$ to $P_6$ inclusive Region 3.  Figure 6 shows these regions and illustrates baseline drift (although in practice it would not be as severe as indicated and would usually be undetectable to the naked eye).

If a least-squares polynomial of low order is fitted to the points in the regions 1 and 3, the result should provide a reasonable way of smoothing out the

noise and representing the unknown baseline drift within the calibration pulse itself.

For convenience, the following notation will be used. Let P represent a distance parameter along the CPDF. If the data points are taken as separated by one unit of distance and the start of the file (P = 0) is taken as one distance unit before the first data point, then P = 1 is the distance of Point 1 from the start of the file. P will then be numerically equal to the Point Number and will measure the distance of a data point from the start of the file. Non-integral values of P will designate the distance of positions between data points from the start of the file.*

The least-squares polynomial $g(P - P_0)$ of order m to be determined using the points in Regions 1 and 3 can be written

$$g(P - P_0) = \sum_{i=1}^{m+1} C_i (P - P_0)^{i-1} \qquad (6.2.4.1)$$

where $P_0$ is a specific value of P. $P_0$ is set internally by SPADE to optimise the accuracy of the least-squares fit but can, in principle, be set arbitrarily. $C_1 \ldots C_{m+1}$ are the coefficients of the polynomial which are determined from the least squares fit (see Appendix C).

With $g(P - P_0)$ determined, it can be used to estimate background value in Region 2. On the pulse top in Region 2, there is a set of discrete data points that were obtained by taking samples at equal time increments from the pulse top on the analog signal. Whilst the analog trace gives an accurate representation

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* In the case of a constant digitizing rate, P could be taken as time measured from the start of a file. In the case of a variable digitizing rate, however, the time scale would be nonlinear with respect to the P scale. It is more general and convenient to consider time as a function of P.

of the signal for the pulse top, the accuracy of the digitized signal depends upon the sampling frequency used. Thus only an approximate function can be constructed to represent approximately the true pulse top. For example, joining all the digitized points along the pulse top with straight lines would be a geometric representation of one possible approximate function for representing the pulse top. Another would be to fit a least-squares polynomial to the pulse top and then to use the polynomial as an approximate function.

For generality, let $y(P - P_0)$ be any approximate function for the pulse top. Then $\bar{h}(DU)$, the average height of the pulse with respect to the baseline, can be determined from (see Figure 6)

$$\bar{h}(DU) = \frac{1}{(P_4 - P_3)} \int_{P_3}^{P_4} [y(P-P_0) - g(P-P_0)] dP \qquad (6.2.4.2)$$

For the evaluation of the integral in Equation 6.2.4.2, SPADE offers two approaches:

a)   Use Simpson's Rule and the known values at the data points on the pulse top. The baseline data points are evaluated using the polynomial $g(P - P_0)$ evaluated at the data points. The use of this rule is equivalent to constructing the approximate function $y(P - P_0)$ with quadratic polynomials as interpolation functions over consecutive groups of three data points. This method will be clarified in Section 6.7 where Simpson's Rule is discussed.

b)   Fit a least-squares polynomial to the points on the pulse top and then use this polynomial as the approximate function $y(P - P_0)$. Equation (6.2.4.2) can then be integrated in closed form to find the average pulse height $\bar{h}(DU)$.

Choice a) will usually be the most accurate and should be chosen in most cases. Specifying various orders of polynomial for the background will then give

an estimate of accuracy. Choice b) can be selected as a check if required. It is important to note, however, that the last value of $\bar{h}(DU)$ calculated is the one that will be used. Thus, if checks on $\bar{h}(DU)$ are carried out, the one required should be re-calculated before leaving the calculation. Once a satisfactory value of $\bar{h}(DU)$ has been calculated, the Scale Factor E is calculated in accordance with Equation (6.2.1.1).

## 6.3 Option 3: Scale the Transducer Signal Data

### 6.3.1 Introduction

The object of Option 3 is to convert the data on the SDF for a specified transducer from digitized units to real units by applying the value of the Scale Factor E computed with Option 2. This value of E is stored on the TDF. SPADE will check that E for the specified transducer has, in fact, been calculated. If it has not, then an information message will be given and Option 2 will be required to be done before Option 3 can be executed.

At the start of Option 3, SPADE will list the transducers that have been defined on the TDF. The Channel and Transducer Code will then be requested to specify the SDF that is to be scaled. A full illustration of the use of this option is given in the sample run in Section 2.3 of Reference 5.

### 6.3.2 Definition of the Signal Definition Points

Figure 7 shows a schematic illustration of a digitized transducer signal with superimposed background drift and noise. Typically the total number of points on the SDF is 5000. As is done for the CPDF, SPADE uses a set of transducer Signal Definition Points (SDP) denoted as $P_1$, $P_2$, $P_3$, $P_4$, $P_5$, and $P_6$. These points are stored on the TDF. $P_1$ to $P_6$ will now be defined.

Points $P_1$ to $P_2$ inclusive will be defined by SPADE as a set of points before the signal that is used for background correction (Region 1). Figure 7 illustrates this definition. Usually $P_1$ will be set to 1 to denote the first

point on the SDF. Also $P_2$ will be set to the point number that defines the start of the signal.

Points $P_3$ and $P_4$ are used only for pressure transducer signals. They are not used for other types of transducer signal in the current version of SPADE. For a pressure signal $P_3$ is set to the Point Number of the maximum pressure and $P_4$ to the Point Number that defines the end of the positive phase. Figure 8 shows a typical type of pressure pulse with $P_3$ and $P_4$ defined.

Points $P_5$ to $P_6$ inclusive define a set of points after the signal (Region 3) that is used for background correction. Usually $P_6$ is be set to 0 to indicate to SPADE that no points after the signal are to be used for background correction.

Points $P_2$ to $P_5$ exclusive will define Region 2. This region contains the actual signal. If $P_5$ is zero, Region 3 does not exist and the end of Region 2 is undefined. For acceleration and strain this is generally the case since some signal is often detectable at the end of the SDF. For pressure signals, it may be possible to define $P_5$.

### 6.3.3  Determination of the Signal Definition Points

$P_1$ is set to 1 and will remain at this value unless explicity changed by the user. SPADE will automatically scan the SDF for the start of the signal and set $P_2$ to the PN found. The technique used to scan for $P_2$ is precisely the same as that used to scan for $P_2$ in the case of the Calibration Pulse. This technique was discussed in Section 6.2.3. A parameter NOISE is again used. The value of NOISE is initially set to 10% but several values should be tried until consistent values for $P_2$ are obtained. For pressure signals which have steep rise times (for pressure transducers on the top surface), values of say 5% and 15% may give results which are consistent with 10%. For strain gauges and accelerometers, it may turn out that values from 1% to 5% will give consistent results. The lower noise level factor that may be required in the latter case for consistent results is due to a slower rise time.

When $P_2$ has been determined, the user is given a choice of checking the results using interactive graphics or a special listing routine that allows direct examination of the data values on the SDF.  At this stage SPADE also allows the user to redefine the definition points $P_1$ and $P_2$.  Points $P_3$ and $P_4$ only apply to pressure pulses and are determined automatically with Option 5. Thus they need not be manually set within this option although they could be if desired.

Points $P_5$ and $P_6$ will usually not be required.  The condition $P_6 = 0$, which is the default value, will flag the condition for no background correction after the signal.  However, SPADE will ask whether background correction is to be applied using points after the signal.  If "Yes" is indicated, $P_5$ and $P_6$ will have to be given for defining Region 3.

## 6.3.4  Background Correction and Scaling of the Signal Data File

With the SDP defined for the SDF, the next step is to correct for background and scale the data to real units.  The processed data will then be placed in the Scaled Signal Data File (SSDF).

Figure 7 shows a schematic illustration of a transducer signal with the background drift and noise exaggerated.  To correct for background, the same procedure as described in Section 6.2.4 for the CP is followed.  For the case of a transducer signal, however, only the points in Region 1 (Figure 7) are usually used for background correction.  The least-squares polynomial is then extrapolated into the signal.  Let $g(P - P_0)$ be the polynomial as defined in Equation (6.2.4.1).  Also let $Y_p$ be the digitized data value of Point P.  Then the data values in real units, denoted by $Z_p$, are given by

$$Z_p = E[Y_p - g(P-P_0)] \qquad (6.3.4.1)$$

where E is the scale factor determined in Option 1 or Option 2.

The real data values, $Z_p$, are written to an SSDF created by SPADE with a

name given according to the file naming convention discussed in Appendix B.  The SDF is not overwritten.

## 6.4  Option 4:  Determine the Start Time for the Pressure Transducer Signals

Each point on the CPDF corresponds to a definite time from the IRIG B signal which provides a common time base for all events.  Let $P^i$ measure distance along the SDF or the SSDF for the i'th transducer on the TDF (recall that, by defini- tion, $P^i$ will be the actual Point Number at a data point since all data points are considered to be equally spaced by 1 unit of distance and $P^i = 0$ is 1 distance unit after the first point).  Also let $T_s^i$ be the start time of digitizing (from the IRIG B signal) for transducer i.  With the digitizing rate $R^i$, the time T corresponding to $P^i$ can be found from the following relation (see Figure 9)

$$T = T_s^i + P^i/R^i$$

$(6.4.1)$

In general, it is not convenient to use the IRIG B time T but rather a new time scale t defined as

$$t = T - T_0$$

$(6.4.2)$

where $T_0$ is an IRIG B time chosen as the $t = 0$ point on the new time scale.  No superscript i is required in Equation (6.4.2) since the IRIG B time scale and the new time scale are common time scales for all transducers.  $T_0$ will correspond to $P_0^i$ from the file start for the i'th transducer, which will usually, although not necessarily, fall within the file limits on Point Number.  For transducer i, for example, we have from Equation (6.4.1)

$$T_0 = T_s^i + P_0^i/R^i$$

$(6.4.3)$

Thus once a $T_0$ has been selected on the IRIG B time scale, $P_0^i$ can be calculated by solving 6.4.3 for $P_0^i$ as

$$P_0^i = R^i(T_0 - T_s^i) \qquad\qquad (6.4.4)$$

It is important to note that, in general, $T_s^i$ will be different for each transducer i.

$T_0$ can essentially be chosen arbitrarily; the choice simply amounts to choosing a common time point for t = 0 for all transducers. SPADE gives two choices for choosing $T_0$. These choices are described as choice I and II below.

I. Choose $T_0$ to be the average IRIG B time of arrival of the pressure pulses from all the pressure transducers on the top surface of the panel. This choice is appropriate for a symmetrically placed charge as shown in Figure 2.

II. Choose $T_0$ as the earliest IRIG B time of arrival of the pressure pulses from a pressure transducer on the top panel surface. This choice would be appropriate if the charge over the plate in Figure 2 was not symmetrically placed.

The choice of I or II should be made for convenience only. Pressure transducers on the top surface are convenient to use in both cases since they are directly exposed to a blast wave and thus have very steep rise times.

The procedure followed by SPADE will now be described. The overall purpose of Option 4 is to determine a $P_0^i$ for each transducer i on a TDF corresponding to a specific Series, Shot, and Panel and to write the values to the TDF. These values can then be used by other options of SPADE and by SPADE-PLOT |4|, to establish an appropriate time base. For the purpose of the following discussion, it will be assumed that transducers i = 1 to $N_P$ are pressure transducers on the top panel surface. The total number of transducers on the TDF is N.

1. Extract the start of digitizing time $T_s^i$ for i = 1 to N from the TDF.

2. Determine the minimum digitizing start time $T_M$ for the pressure trans-

ducers on the top surface.  Thus $T_M$ = minimum of $T_s^i$ for i = 1 to $N_p$.

3.   For all transducers i = 1 to N

$$\text{Set } T_s^i \dashrightarrow T_s^i - T_M \qquad\qquad (6.4.5)$$

This just shifts the zero point on the IRIG B time scale for computational convenience.  In steps 4 to 6, reference to IRIG B time will be assumed measured from this new starting point.

4.   Calculate, for i = 1 to $N_p$, from Equation (6.4.1)

$$T_a^i = T_s^i + P_2^i/R^i \qquad\qquad (6.4.6)$$

where $P_2^i$ is the second SDP for the i'th pressure transducer.  $T_a^i$ is then the IRIG B time (measured from the minimum digitizing start time) for the start of the pressure pulse.

5.   If choice I is being considered for determining $T_0$, set

$$T_0 = (\sum_{i=1}^{N_p} T_a^i)/N_p \qquad\qquad (6.4.7)$$

$T_0$ is then the average time of arrival of the pressure pulses.

If choice II is being considered, set $T_0$ to the minimum of the $T_a^i$ values.  $T_0$ will then be the first time of arrival of a pressure pulse.

6.   For i = 1 to N calculate the $P_0^i$ values for all transducers from Equation (6.4.4).  The values of $P_0^i$ then define the Point Numbers on the SDF and SSDF that correspond to the t = 0 point.

## 6.5   Option 5:   Determine Pressure Signal Characteristics

### 6.5.1   Introduction

Figure 10 shows a typical pressure pulse as would be detected by a pressure gauge exposed directly to a blast wave.  The curve represents a plot of overpressure against time t.  It is the purpose of this option to determine the pressure pulse characteristics that are indicated in Figure 10.

Section 6.5.2 will first review the definitions of the pressure pulse characteristics indicated in Figure 10.  Section 6.5.3 will present various functional relations that can be used to approximate pressure pulses.  Finally, Sections 6.5.4 and 6.5.5 will discuss how SPADE uses the various functional relations to describe pressure signals.

### 6.5.2   Definition of Pressure Pulse Characteristics

The pressure pulse illustrated schematically in Figure 10 is of typical shape (Reference 6, page 111 or Reference 7, pages 4 - 8) and represents an undisturbed or side-on shock wave as it propagates through the air.  The pressure pulse, when detected by a pressure guage, will have a certain time of arrival $T_a$. For $T < T_a$ the pressure is zero relative to ambient pressure.  For $T > T_a$ a steep rise in pressure occurs to a maximum at time $T_a + T_r$ known as the peak overpressure (or peak side-on overpressure) $P_s^+$.   $T_r$ is known as the rise time and is assumed to be zero for an ideal blast wave.  After the maximum has been reached, the pressure pulse decays to zero and then becomes negative to a maximum negative amplitude of $P_s^-$ known as the peak underpressure.  If the time at which the pressure pulse becomes negative is $T_a + T^+$, then $T^+$ is referred to as the positive phase duration.  For $T_a + T^+ < T < T_a + T^+ + T^-$ the negative phase (or suction phase) occurs; that is, a partial vacuum exists behind the shock front.  $T^-$ is known as the negative phase duration.   For $T > T_a + T^+ + T^-$ the pressure is assumed to remain at zero.

The positive specific impulse, $i_s^+$, is the area under the positive phase of the curve and represents the impulse per unit area. Thus, $i_s^+$ is defined as

$$i_s^+ = \int_{T_a}^{T_a+T^+} P(t)dt \qquad (6.5.2.1)$$

and $i_s^-$, the negative specific impulse, is defined as

$$i_s^- = -\int_{T_a+T^+}^{T_a+T^++T^-} P(t)dt \qquad (6.5.2.2)$$

SPADE calculates the following pressure signal characteristics directly from the experimental data:  the time of arrival, peak overpressure, rise time, positive phase duration and positive specific impulse. In addition, the signal definition points $P_3$ and $P_4$ are calculated to indicate the time of peak overpressure and the end of the positive phase, respectively. These two additional points are written to the TDF and allow $T_r$ and $T^+$ to be calculated when required. In addition, the pressure SSDF is integrated to give a corresponding file containing specific impulse against time from which the maximum specific impulse and the time of occurrence can be determined.

### 6.5.3  Functional Forms Used to Approximate Pressure Signals

The following functional forms for representing pressure pulses are taken from Reference 7.

For the positive phase only

$$P(t^-) = P_s^+ \exp(-b_0 t^-/T^+) \qquad (6.5.3.1)$$

where $b_0$ is a constant known as the decay constant. $t^-$ is the time measured from $T_a+T_r$ (thus $t^-=T-T_a-T_r$). This function can be used to obtain a reasonably good fit usually over at least 50% of the positive phase.

For both the positive and negative phase a very crude linear approximation is

$$P(t^-) = P_s^+(1-t^-/T^+) \qquad\qquad (6.5.3.2)$$

If Equation (6.5.3.2) is combined with Equation (6.5.3.1) however, a much improved relation results as follows:

$$P(t^-) = P_s^+(1-t^-/T^+) \exp(-b_0 t^-/T^+) \qquad\qquad (6.5.3.3)$$

Equation (6.5.3.3) is sometimes referred to as the modified Friedlander equation [6]. This functional form will usually give a reasonable fit to experimental data up to a time $T=T_a+3T^+/2$.

In Equation (6.5.3.3) the decay constant $b_0$ is assumed to be constant. An improvement is obtained if a time dependent decay constant b is introduced and assumed to be a function of time $t^-$ as

$$b = b_0\left| 1 + \frac{g}{1+h(\frac{t^-}{T^+})} \right| \qquad\qquad (6.5.3.4)$$

where g and h are constants. A somewhat simpler but more restrictive form is sometimes adequate as follows:

$$b = b_0\left[1 - f(\frac{t^-}{T^+})\right] \qquad\qquad (6.5.3.5)$$

where f is a constant.

An equation for $P(t^-)$ that is known to give an excellent fit to experimental blast waves is [7]

$$P(t^-) = P_s^+ \left[ 1 - \left( \frac{t^-}{T^+} \right) \right] \left[ a e^{-\alpha t^-/T^+} + (1-a) e^{-\beta t^-/T^+} \right] \qquad (6.5.3.6)$$

where a, $\alpha$ and $\beta$ are constants.

Whilst Equations (6.5.3.3) and (6.5.3.6) are valid for both the positive and negative phases, the negative phase may not be fitted with good accuracy. An equation that is known to give a good fit to the negative phase is

$$P(t) = -P_s^- \left( \frac{t-T^+}{T^-} \right) \left( 1 - \frac{t-T^+}{T^-} \right) \exp \left[ -4 \frac{(t-T^+)}{T^-} \right] \qquad (6.5.3.7)$$

where t is now measured from $T^+$.

## 6.5.4  Direct Calculation of Pressure Pulse Parameters

All of the equations (6.5.3.1) to (6.5.3.3) and (6.5.3.6) involve $P_s^+$ and $T^+$. Any remaining constants can be determined by using the experimental data and the appropriate equations. For example, Equation (6.5.3.2) can be integrated to give an expression for $i_s^+$. $T^+$ in the equation can then be determined using the $i_s^+$ found by integration of the experimental values. Thus if $P(t^-)$ given by (6.5.3.2) is substituted into Equation (6.5.2.1) and the resulting equation for $i_s^+$ is solved for $T^+$ there results

$$T^+ = \frac{2 i_s^+}{P_s^+} \qquad (6.5.4.1)$$

The experimental value of $i_s^+$ found by integration of the pressure time data can then be substituted into Equation (6.5.4.1) together with an experimental value of $P_s^+$ to give $T^+$.

A similar procedure can be followed for Equation (6.5.3.1). If $i_s^+$ is calculated using Equation (6.5.3.1), the following equation is obtained.

$$\exp(-b_0) + \frac{i_s^+}{P_s^+ T^+} b_0 = 1 \qquad (6.5.4.2)$$

In this case $i_s^+$, $P_s^+$ and $T^+$ could be supplied and the nonlinear Equation (6.5.4.2) solved iteratively for $b_0$. This value of $b_0$ would then guarantee that $i_s^+$ calculated with Equation (6.5.3.1) be the same as the experimental value.

In the case of Equation (6.5.3.3) a more complicated relation results.

$$\exp(-b_0) + \frac{P_s^+ T^+ - i_s^+ b_0}{P_s^+ T^+} b_0 = 1 \qquad (6.5.4.3)$$

Again, $i_s^+$, $P_s^+$ and $T^+$ could be supplied to calculate a $b_0$. Other possibilities would be to also calculate $i_s^-$ and then to determine $T^+$ to match the experimental $i_s^-$.

SPADE offers facilities for calculating the constants in equations (6.5.3.1) to (6.5.3.3) using the procedures mentioned. $T^+$ can be determined from (6.5.4.1). $i_s^+$ and $P_s^+$ are calculated from the experimental data on the SSDF. $b_0$ is calculated from equations (6.5.4.2) or (6.5.4.3) using experimental values of

$P_s^+$, $T^+$ and $i_s^+$.

## 6.5.5  Least Squares Calculation of Parameters

SPADE also allows the parameters in Equations (6.5.3.1) and (6.5.3.3) to be calculated using least squares. The advantage of this technique is that all experimental data points can be used to estimate the parameters. The approach taken will now be outlined for the case of Equation (6.5.3.1).

Equation (6.5.3.1) is repeated below for convenience.

$$P(t^-) = P_s^+ \exp\left(-b_0\frac{t^-}{T^+}\right) \qquad (6.5.3.1)$$

Taking the natural logarithm of both sides then gives

$$\ln(P) = \ln(P_s^+) - b_0\frac{t^-}{T^+} \qquad (6.5.5.1)$$

Values of P for each time point on the SSDF are available. Thus if a linear least squares fit for points $[t', \ln(P)]$ is done over a selected region of the positive duration, the slope of the straight line obtained will give $b_0/T^+$ and the ordinate intercept will give $\ln(P_s^+)$. Thus, provided a $T^+$ is available or can be estimated, $b_0$ can be found and, of course, $P_s^+$ can be found by taking the exponential of $\ln(P_s^+)$.

If the parameters are determined by this procedure, SPADE will request values of $E_1$ and $E_2$ to define the fraction of the time domain (Ta+Tr to Ta+$T^+$) to be used to do the least squares fit. Only points on the pressure SSDF with PN's between $E_1(P_4-P_3) + P_3$ and $E_2(P_4-P_3) + P_3$, inclusive, will be used in the least squares fit. As indicated in Section 6.5.2, the SDP $P_3$ and $P_4$ identify the position of maximum pressure and positive duration, respectively.

The calculation for $P_s^+$ and $b_o$ by this procedure is outlined in the sample run in Section 2.5 of Reference 5. Interactive graphics are very useful in this option for determining whether the values found are satisfactory. Figure 11 illustrates a series of plots obtained with interactive graphics. Figures 11(a) to 11(c) indicate a fit to a pressure pulse with $E_1 = 0$, and $E_2 = 0.3$ which are typical and the suggested (default) values. There are about 100 points in the positive phase. An excellent fit is obtained over about one half the positive phase. The result over the whole positive phase is quite good in fact.

The interactive graphics procedure allows "windowing" to be done with the graphics cursor. The small box indicates the portion to be windowed. Figure 11(c) indicates the result after windowing to the limit of digitizing. The digitized points can be clearly seen joined with straight lines.

Figure 11(d) shows the result of using $E_1 = 0$, $E_2 = 0.8$. Because points in the latter part of the positive duration are used, a loss of accuracy occurs for point numbers 0 to 20. This result would thus not be acceptable since a good fit should be obtained for at least the first one third of the positive duration.

## 6.6  Option 6:  Integrate Acceleration to Obtain Relative Velocity

### 6.6.1  Introduction

This option requires very little interaction of the user with SPADE. An SSDF containing accelerometer output can be integrated in time to obtain an SSDF containing velocity. Simpson's integration technique [8] is used but not in the standard way. The required formulas will be developed in this section.

### 6.6.2  Theory

To find velocity it is necessary to integrate acceleration with respect to time t. If R is the digitizing rate, there are $1/R$ $(=h)$ time units between each sample on the SSDF. Let $P_o$ be the point number on the SSDF corresponding to

t = 0.  Then the time t at point P is

$$t = h(P-P_0) \qquad (6.6.2.1)$$

Let $y(t)$ represent the true acceleration at a time t on the SSDF containing accelerations.  Because of the finite sampling rate in the digitizing process $y(t)$ is only known when $t = t_i$, where $t_i$ is the time corresponding to the i'th point number.  To construct an approximate acceleration function, quadratic interpolation will used to give values of acceleration between sample points. Figure 12(a) illustrates this approximation procedure.  The SSDF is assumed to contain only seven points in this case.  The solid curve represents the true $y(t)$ which is only actually known at the data points.  The dotted curve represents $\tilde{y}(t)$, an approximate function.  Points 1 to 3 have a single quadratic polynomial through them (3 points will determine a quadratic polynomial uniquely).  Points 3 to 5 have a second quadratic through them and Points 5 to 7 a third.  The first and second quadratic have a common value at Point 3 but the slopes do not match. The same situation occurs at Point 5.  $\tilde{y}(t)$ is thus a continuous function but is only piecewise differentiable since the slope is discontinuous at points where the quadratics are joined.  $\tilde{y}(t)$ can thus be integrated in a piecewise fashion to provide an approximation to the integation of the true acceleration $y(t)$.

To develop the formulas necessary for integration, consider the region in Figure 12(b) defined by the points corresponding to times $t_1$, $t_1+h$, and $t_1+2h$. Let the quadratic polynomial defining the acceleration over this region be defined as

$$\tilde{y}_1(t) = b_1+b_2(t-t_1)+b_3(t-t_1)^2 \qquad (6.6.2.2)$$

The coefficients $b_1$, $b_2$ and $b_3$ in Equation (6.6.2.2) can be found by substituting $t = t_1$, $t = t_1 + h$ (or $t_2$), and $t = t_1 + 2h$ (or $t_3$) into Equation (6.6.2.2).  The conditions $\tilde{y}_1(t_1) = y_1$, $\tilde{y}_1(t_2) = y_2$, and $\tilde{y}_1(t_3) = y_3$, where $y_1$, $y_2$, and $y_3$ are known values of accleration, determine the coefficients $b_1$, $b_2$, and $b_3$ uniquely as

$$b_1 = y_1 \tag{6.6.2.3}$$

$$b_2 = \frac{4y_2 - 3y_1 - y_3}{2h} \tag{6.6.2.4}$$

$$b_3 = \frac{y_1 - 2y_2 + y_3}{2h^2} \tag{6.6.2.5}$$

The next step is to derive an expression for $\tilde{y}_1(t)$ integrated from $t_1$ to $t_1+h$ and $t_1+2h$. For generality let

$$I_{t_1}^{t_1+\alpha h} = \int_{t_1}^{t_1+\alpha h} \tilde{y}(t)dt \tag{6.6.2.6}$$

where $\alpha$ is a fraction of the time h between two data points. If Equation (6.6.2.2) is substituted into (6.6.2.6) and the equations (6.6.2.3) to (6.6.2.5) are utilized, one can show after a straightforward reduction that

$$I_{t_1}^{t_1+\alpha h} = h\alpha(1 - \frac{3}{4}\alpha + \frac{1}{6}\alpha^2)y_1 + h\alpha^2(1 - \frac{1}{3}\alpha)y_2 + h\alpha^2(\frac{1}{6}\alpha - \frac{1}{4})y_3 \tag{6.6.2.7}$$

Thus, setting $\alpha = 1$ gives

$$I_{t_1}^{t_1+h} = \frac{h}{12}(5y_1 + 8y_2 - y_3) \tag{6.6.2.8}$$

and setting $\alpha = 2$ gives

$$I_{t_1}^{t_1+2h} = \frac{h}{3}(y_1 + 4y_2 + y_3) \tag{6.6.2.9}$$

Thus

$$I_{t_1+h}^{t_1+2h} = I_{t_1}^{t_1+2h} - I_{t_1}^{t_1+h} = \frac{h}{12} (-y_1 + 8y_2 + 5y_3) \qquad (6.6.2.10)$$

Equations (6.6.2.8) and (6.6.2.10) are the equations utilized by SPADE to integrate acceleration to obtain velocity. Equation (6.6.2.8) allows an integration over the first half of the interval shown in Figure 12(b) and (6.6.2.10) over the second half. Thus by integrating over each individual segment in each of the three regions in Figure 12(a) the velocity at each time point can be found. Thus

$$V_2 = I_{t_1}^{t_1+h} = \frac{h}{12} (5y_1 + 8y_2 - y_3)$$

$$V_3 = I_{t_1}^{t_1+2h} = I_{t_1}^{t_1+h} + \frac{h}{12} (-y_1 + 8y_2 + 5y_3)$$

$$V_4 = I_{t_1}^{t_1+3h} = I_{t_1}^{t_1+2h} + \frac{h}{12} (5y_3 + 8y_4 - y_5)$$

$$V_5 = I_{t_1}^{t_1+4h} = I_{t_1}^{t+3h} + \frac{h}{12} (-y_3 + 8y_4 + 5y_5)$$

$$\cdot$$
$$\cdot$$
$$\cdot$$

Thus velocities at <u>all</u> the discrete time points can be obtained.

It is perhaps worth mentioning that Equation (6.6.2.9) is usually the way that the Simpson's Rule is presented; that is, $\alpha$ in Equation (6.6.2.7) is restricted to being an even number. The advantage of using the more general form in Equation (6.6.2.7) is that $\alpha$ can be chosen to be any value from 0 to 2 inclusive. Thus, if required, any number of points within each region can be

chosen at which the velocity is required. As indicated above, however, SPADE only evaluates the velocities at the same time points for which the acceleration is defined.

### 6.6.3  SPADE Processing for Velocity

SPADE will initially request the Series, Panel, and Shot numbers as usual. After Option 6 has been flagged, SPADE will request the Channel Number and Transducer Code. If the Transducer Code does not correspond to an accelerometer, SPADE will request the Channel Number and Transducer Code to be respecified. Also, since the integation is done from the t = 0 position on the SSDF (time $T_o$ on IRIG B), SPADE will check that $P_o^i$ has been determined with Option 4 (see Section 6.4). On completion of the integration, SPADE will indicate that the file containing the velocities has been created. The original acceleration SSDF is not overwritten; a new file referred to as a Derived Velocity Signal File (DVSF) is created with a file name according to the convention in Appendix B2. The format of the DVSF is identical to that of the corresponding SSDF containing the accelerations. Thus if $Y_N$ on the SSDF is the acceleration at the N'th PN, then on the DVSF it is the velocity at the same PN.

### 6.7  Option 7:  Integrate Velocity to Obtain Relative Displacement

This option is esentially identical to Option 6. In this case, however, there are two choices:  1) To integrate an SSDF containing data from a velocity transducer or 2) To integrate a DVSF. In each case, SPADE will check that Option 4 has been completed so that integration can be carried out from the t = 0 position. On completion of the integration, SPADE will indicate that the file containing the relative displacements has been created. The original velocity SSDF (choice 1) or DVSF (choice 2) is not overwritten; a new file referred to as a Derived Displacement Signal File (DDSF) is created. The file naming convention discussed in Appendix B2 will distinguish a DDSF as having been created from an SSDF containing velocities or a DVSF. The format of the DDSF is identical to that of the corresponding SSDF or DVSF. Thus if $Y_N$ on the SSDF or DVSF is the

velocity at the N'th point number, then on the DDSF it is the displacement at the same time point. It is worth noting that displacement data may be recorded during the tests using displacement measuring transducers. This displacement data would be placed on a SSDF according to the above file format and the file would be named by the convention presented in Appendix B2.

## 6.8 Option 8: Obtain Acceleration, Velocity and Displacement Based on Fit to Displacement

### 6.8.1 Introduction

In the execution of Option 6 and Option 7, several effects are produced due to background noise effects and possibly unknown initial conditions. For example, if a signal constant in time is superimposed on an acceleration signal, the velocity signal will have a signal linear in time superimposed on it. Similarly, because of double integration, the displacement signal will have a signal quadratic in time superimposed on it. Although Option 3 will correct for background to a significant extent, small non-zero acceleration baseline effects may still be present and turn out to be significant.

Another effect that can cause extraneous results is unknown initial conditions. An acceleration signal from an accelerometer can only be used to extract information on changes of velocity. After execution of Option 6, the resulting DVSF will only contain relative velocities. Unless the initial velocity is zero, the Derived Velocity Signal (DVS) will require a signal constant in time to be superimposed on it to give the correct initial velocity. This will then cause a signal linear in time to be superimposed on the Derived Displacement Signal (DDS).

In Section 6.8.2, the above considerations will be presented in more detail together with the method used by SPADE to obtain corrected accelerations, velocity, and displacement signals. Section 6.8.3 will then describe how SPADE proceeds with Option 8.

## 6.8.2  Theory and Method of Correction

Before proceeding with a description of this option, it will be useful to define an integration operator, $I_0^t$.  If $f(t)$ is a function of time, $I_0^t$ is defined as

$$I_0^t f(t) = \int_0^t f(x) dx \qquad (6.8.2.1)$$

where x is a dummy variable of integration.  The operation can also be repeated as follows:

$$I_0^t I_0^t f(t) = \int_0^t \int_0^y f(x) dx dy \qquad (6.8.2.2)$$

y is another dummy variable of integration.

Now let $a(t)$ be the true acceleration time signal for a point on a structure.  Also let $\tilde{a}(t)$ be the measured value of acceleration.  Then the measured acceleration time signal $\tilde{a}(t)$ can be regarded as the true acceleration time signal with a superimposed error signal $\tilde{\varepsilon}^a(t)$.  Thus

$$\tilde{a}(t) = a(t) + \tilde{\varepsilon}^a(t) \qquad (6.8.2.3)$$

When Option 6 is carried out, the SSDF containing sampled values of $\tilde{a}(t)$ is used to create a DVSF containing values of $\bar{v}(t)$, the derived relative velocities.  From Equation (6.8.2.3) we can write

$$\bar{v}(t) = I_0^t \tilde{a}(t) = I_0^t a(t) + I_0^t \tilde{\varepsilon}^a(t) \qquad (6.8.2.4)$$

Now $I_0^t a(t) = v(t) - v(o)$ where $v(t)$ is the true velocity obtained from $a(t)$ by integration and $v(o)$ is the true value of velocity at $t = 0$.  Thus Equation (6.8.2.4) can be written

$$\bar{v}(t) = v(t) - v(o) + I_0^t \, \tilde{\varepsilon}^a(t) \qquad (6.8.2.5)$$

It should be emphasized that as a result of Option 6, only $\bar{v}(t)$ is actually calculated. The quantities on the right hand side of Equation (6.8.2.5) are not actually known.

When Option 7 is executed, the values of $\bar{v}(t)$ on the DVSF are used to calculate $I_0^t\bar{v}(t)$ or $\bar{\bar{d}}(t)$, the derived relative displacements found from $\bar{v}(t)$. Thus, from Equation (6.8.2.5) we can write

$$\bar{\bar{d}}(t) = I_0^t\bar{v}(t) = I_0^t v(t) - I_0^t v(o) + I_0^t I_0^t \, \tilde{\varepsilon}^a(t) \qquad (6.8.2.6)$$

Since $I_0^t \, v(t) = d(t) - d(o)$ and $I_0^t \, v(o) = v(o)t$, Equation 6.8.2.6 can be written

$$\bar{\bar{d}}(t) = d(t) - d(o) - v(o)t + I_0^t I_0^t \, \tilde{\varepsilon}^a(t) \qquad (6.8.2.7)$$

$d(t)$ represents true displacement at time $t$, and $\bar{\bar{d}}(t)$ approximate relative displacement at time $t$ found from $\bar{v}(t)$. In equations (6.8.2.5) and (6.8.2.7), the actual unknowns are $v(t)$ and $d(t)$, respectively. The equations can thus be re-written

$$v(t) = \bar{v}(t) - [I_0^t \, \tilde{\varepsilon}^a(t) - v(o)] \qquad (6.8.2.8)$$

and

$$d(t) = \bar{\bar{d}}(t) - [I_0^t I_0^t \, \tilde{\varepsilon}^a(t) - v(o)t - d(o)] \qquad (6.8.2.9)$$

The quantities in square brackets are then correction terms that must be applied to extract the true values of $v(t)$ and $d(t)$. Let

$$\tilde{\varepsilon}^v(t) = I_0^t \, \tilde{\varepsilon}^a(t) - v(o) \qquad (6.8.2.10)$$

and

$$\overset{=d}{\varepsilon}(t) = I_0^t I_0^t \overset{\sim a}{\varepsilon}(t) - v(o)t - d(o) \tag{6.8.2.11}$$

Then equations (6.8.2.3), (6.8.2.8) and (6.8.2.9) can be written

$$a(t) = \widetilde{a}(t) - \overset{\sim a}{\varepsilon}(t) \tag{6.8.2.12}$$

$$v(t) = \overline{v}(t) - \overset{-v}{\varepsilon}(t) \tag{6.8.2.13}$$

$$d(t) = \overline{\overline{d}}(t) - \overset{=d}{\varepsilon}(t) \tag{6.8.2.14}$$

The correction procedure thus involves determining $\overset{\sim a}{\varepsilon}(t)$, $\overset{-v}{\varepsilon}(t)$, and $\overset{=d}{\varepsilon}(t)$ so that the true signals can be extracted from the approximate ones.

Before proceeding further a simple, but most common, case will be considered. Suppose $\overset{\sim a}{\varepsilon}(t)$ is just constant in time; that is, $\overset{\sim a}{\varepsilon}(t) = \psi$ where $\psi$ is a constant. Then Equation (6.8.2.10) shows that

$$\overset{-v}{\varepsilon}(t) = \psi t - v(o) \tag{6.8.2.15}$$

and Equation (6.8.2.11) shows that

$$\overset{=d}{\varepsilon}(t) = \frac{1}{2}\psi t^2 - v(o)t - d(o) \tag{6.8.2.16}$$

Thus the $\overset{-v}{\varepsilon}(t)$ is just a polynomial of order 1, a linear variation, and $\overset{=d}{\varepsilon}(t)$ is a polynomial of order 2, a quadratic variation.

For generality it will now be assumed that $\overset{=d}{\varepsilon}(t)$ can be represented adequately as a polynomial of order m:

$$\overset{=d}{\varepsilon}(t) = \sum_{J=1}^{m+1} \overset{=d}{C}_J t^{J-1} \tag{6.8.2.17}$$

Once the coefficients $\bar{\bar{C}}_J^d$ have been found, Equation (6.8.2.14) can be used to find an approximation to the actual displacements $d(t)$. In order to calculate the coefficients it is proposed to use a least squares procedure as outlined in Appendix C. Now, on completion of Option 7, a DDSF will have been created containing $\bar{d}_N$ values, where $\bar{d}_N$ is the approximate relative displacement at the N'th PN. Let a least squares polynomial

$$\bar{\bar{d}}(t) = \sum_{J=1}^{m+1} \bar{\bar{C}}_J t^{J-1}$$

(6.8.2.18)

be fitted to N data points starting at PN $P_0$ (for $t = 0$) on the DDSF. Thus we want to fit the polynomial in the least squares sense to the data points $(t_{P_0+K}, \bar{d}_{P_0+K})$ for $K = 0$ to $N - 1$. It should be recalled that the $t_{P_0+K}$ values can be calculated from Equation (6.6.2.1) as

$$t_{P_0+K} = hK$$

(6.8.2.19)

where h is the reciprocal of the digitizing rate. From equations (C3.5) to (C3.7) in Appendix C, we have to solve the system of equations

$$\sum_{J=1}^{m+1} \bar{\bar{A}}_{IJ}\bar{\bar{C}}_J = \bar{\bar{B}}_I$$

(6.8.2.20)

for $I = 1, 2, \ldots m+1$

where

$$\bar{\bar{A}}_{IJ} = \sum_{K=0}^{N-1} t_{P_0+K}^{I+J-2}$$

(6.8.2.21)

and

$$\bar{\bar{B}}_I = \sum_{K=0}^{N-1} \bar{\bar{d}}_{P_o+K} t_{P_o+K}^{I-1} \qquad (6.8.2.22)$$

Since the $(t_{P_o+K}, \bar{\bar{d}}_{P_o+K})$ values are available on the DDSF, $\bar{\bar{A}}_{IJ}$ and $\bar{\bar{B}}_I$ can be calculated and Equation (6.8.2.20) solved for the m+1 coefficients $\bar{\bar{C}}_J$.

The next step is to derive the coefficients $\bar{\bar{C}}_J^d$ in Equation (6.8.2.17) from the coefficients $\bar{\bar{C}}_J$. If Equation (6.8.2.14) is used to substitute for $\bar{\bar{d}}_{P_o+K}$ in Equation (6.8.2.22) and then Equation (6.8.2.17) is used to substitute for $\bar{\bar{\epsilon}}_{P_o+K}^d$, it can be shown after a straightforward reduction that

$$\sum_{J=1}^{m+1} \bar{\bar{A}}_{IJ}(\bar{\bar{C}}_J - \bar{\bar{C}}_J^d) = B_I \qquad (6.8.2.23)$$

for I = 1 to m+1

where

$$B_I = \sum_{K=0}^{N-1} d_{P_o+K} t_{P_o+K}^{I-1} \qquad (6.8.2.24)$$

Displacements in structural response are often oscillatory about a zero displacement baseline as shown in Figure 13. Under these conditions, the moments $B_I$ will oscillate about zero when considered as functions of N. Although all the $B_I$ will not in general be zero for the same N, it will usually be the case in practice that an average N can be found such that all the $B_I$ are sufficiently close to zero. It will then be true from Equation (6.8.2.23) that $\bar{\bar{C}}_J \approx \bar{\bar{C}}_J^d$ for J = 1 to M + 1. $\bar{\bar{\epsilon}}^d$ (t) can then be evaluated from Equation (6.8.2.17) and the correction applied to all points $\bar{\bar{d}}_{P_o+k}$ on the DDSF to find d(t).

## 6.8.3  SPADE Processing

Figure 14(a) shows a typical acceleration trace from an accelerometer. Figure 14(b) shows a plot of the derived relative displacements $\{\bar{d}\}$. It appears that the displacements in this case are superimposed on a parabolic type of background variation as anticipated in Equation (6.8.2.16) for the case of $\tilde{\epsilon}^a(t) = \psi$ (a constant error offset of the acceleration trace).

The following procedure is followed by SPADE for this option after the usual preliminary questions regarding the Series, etc., have been answered.

a)   SPADE requests a time $(t_e)$ to define the range of samples on the DDSF to be used in the least squares fit for the determination of the coefficients $\bar{\bar{C}}_J$ for J = 1 to m+1 in Equation (6.8.2.18). $t_e$ should be chosen to be 5 (or greater if possible) and at an integral number of cycles from t = 0.

b)   SPADE will next ask whether m = 2 for the polynomial to be fitted is acceptable. This should usually be answered "yes" unless there is a reason to choose a higher or lower order. The program then proceeds to do the least squares fit with equations (6.8.2.20) to (6.8.2.22). On completion of the fit, the coefficients $\bar{\bar{C}}_J$ are used as the $\bar{\bar{C}}_J^d$ in Equation (6.8.2.17). Equation (6.8.2.14) is then used to calculate an improved approximation to d(t).

The polynomial (6.8.2.17) is next differentiated with respect to time to give $\bar{\epsilon}^V(t)$. If the usual option of using a second order polynomial in item "b" was chosen, $\bar{\epsilon}^V(t)$ will then be a polynomial of order 1 (a linear function). Equation (6.8.2.13) is then used by SPADE to correct the velocities on DVSF. The polynomial for $\bar{\epsilon}^V(t)$ is then differentiated again to give $\tilde{\epsilon}^a(t)$. If $\bar{\epsilon}^V(t)$ is linear then $\tilde{\epsilon}^a(t)$ will just be a constant. Equation (6.8.2.12) is then used to calculate a(t).

Figure 15(a) and 15(b) show the results for the case in Figure 14(b). In this case $\psi$ in Equation (6.8.2.16) turned out to be only about 2 G [9]. This amount is much less than the accuracy to be expected from the accelerometers but leads to a significant improvement in the results as shown in Figure 15(b).

If a graphics terminal is being used, SPADE will optionally plot out the graphs shown in Figures 14(b) and 15(b) for the displacements. The graphs for velocity will also optionally be plotted both before and after correction.

c)   On examining the graphs the user must next decide whether the predicted initial conditions for velocity and displacement are reasonable. Referring to equations (6.8.2.10) and (6.8.2.11), for example, it is seen that the least squares fit to $\bar{\bar{\epsilon}}^d(t)$ will have produced values for v(o) and d(o).

SPADE will ask whether the initial conditions are satisfactory. If not, the program will ask whether v(o) is to be specified. If "yes" is given, the program will request v(o), apply the required vertical shift of the baseline on the DVSF, and then apply a correction to the values on the DDSF to account for the change in the term v(o)t in Equation (6.8.2.11). The program will next ask whether d(o) is to be changed. If "yes" is given, the program will request d(o), apply the required vertical shift of the baseline on the DDSF, and then apply a correction to the values on the DDSF to account for the change in d(o) in Equation (6.8.2.11).

In conclusion, the correction procedure offered in Option 8 has been found to be considerably effective in correcting displacements found from integrating acceleration signals. Although the discussion above assumed elastic response, the present version of SPADE has additional procedures that allow corrections to be applied for large deformation plastic response.

## 6.9  Option 9:  FFT and/or Filtering of Transducer Signals

The Fast Fourier Transform Algorithm (FFT) originated with J.W. Cooley and J.W. Tukey [10].  SPADE uses a Fortran subroutine presented by E.A. Robinson [11] to calculate the Fourier Transform of a specified transducer signal.  A sample run of SPADE for this option is presented in Section 2.9 of Reference 5. SPADE-PLOT is then used to plot the transducer time signal and the associated amplitude ratio against frequency.

## 6.10 Option 10:  Create Averaged Pressure File and VAST Load File

The purpose of Option 10 is to create a load file for the program VAST [1] from pressure transducer signals.  This option will generate a pressure loading for each element of a finite element mesh.  A sample run is presented in Section 2.10.2 of Reference 5.

## 6.11 Option 11:  Extract Displacement, Velocity, and Accewleration from VAST file for Plotting

During the execution of the VAST finite element code, quantities such as displacement, velocity, and acceleration will be copied to a file designated as XXXX_T52, where XXXX is a four character VAST file prefix.  This file will contain kinematic variables for all degrees of freedom at every node and thus could be quite large.

For the purposes of the SPADE program it is convenient to introduce the convention of a Finite Element Transducer Channel.  Tranducer channels were discussed in Section 3.4 and depicted in Figure 2.  A Finite Element Channel is assigned numbers in excess of 500 and, for the purposes of SPADE, will be assumed connected to a fictitous transducer which produces a signal that corresponds to the finite element predictions.  Although Finite Element Tranducers can be defined independently of any real transducer, for correlation studies they will usually be defined to be spatially coincident with some real transducer.  In this case, it is convenient, although not necessary, to define the FE Transducer Code

to be the same as the real one.  Thus in Figure 2, for example, the real
transducer A2 is connected to channel 7.  The corresponding FE Transducer would
have the same Transducer Code, A2, but the Channel Number would be set to 507.
Other quantities, such as the Transducer Coordinates, would then be the same for
both real and FE transducers.

The purpose of Option 11 is to create a Finite Element Signal Data File          .
(FESDF) from the file XXXX_T52 created by VAST.  The FESDF's have the same
format as the scaled Signal Data Files and are given names according to the file
naming convention in Appendix B2.  Once the FESDF has been created, it can be
processed and plotted using SPADE and associated plotting programs.  The FESDF is
essentially considered to contain a signal from the fictitous Finite Element
Transducer.


## 7.   DISCUSSION OF A TYPICAL RUN OF SPADE

The purpose of Section 7 is to summarize briefly the steps involved in using
the SPADE program for processing digitized data files from an experiment.
Reference 5 presents considerably more detail and is intended to guide the reader
explicitly through a series of sample runs.

The first step in processing the data from an experiment is to create the
Transducer List File (TLF) and the Transducer Database File (TDF) with Option 1.
Sections B3 and B4 in Appendix B describe the format of these files.  In
particular, Table B4.1 gives the format of the actual data stored on the TDF.
These files will be given a name according to the convention described in
Section B2

Prior to running Option 1, the CDS shown in Table 5.1 should be completed.
Excuting SPADE will then allow considerable flexibility in the way data can be
entered.

When Option 1 has been completed, the next step is to determine the Signal Scale Factors from the Calibration Pulses with Option 2. To do this for a transducer, SPADE will first determine the CPDP as discussed in Section 6.2.3. This will then be followed by a determination of the calibration pulse height, $\bar{h}$, from equation 6.2.4.2, once the order of the polynomial for the background has been specified. Equation 6.2.1.1 is then used to determine E from the CALIBRATE stored on the TDF.

When all the Signal Scale Factors have been determined, Option 3 can be run for each transducer to obtain the Scaled Signal Data Files. This will involve correcting the signals for drift and then multiplying all the data values by the appropriate Signal Scale Factors.

The next step in the processing should be to synchronise all the transducer signals in time with Option 4. This is done by determining a point on each SSDF that corresponds to a common real time value. This common time value is arbitrarily associated with $t = 0$. In order to make the choice of $t = 0$ physically meaningful, SPADE offere two choices: a) the average time of arrival of the pressure pulses for selected pressure transducers, or b) the first time of arrival.

Option 5 should next be executed to determine the pressure pulse characteristics such as the positive duration, rise time, decay constant, and maximum impulse. Interactive graphics should be used in this option for the best results.

Option 6 should next be executed for all accelerometers to obtain the relative velocity files. Option 7 should then be executed similarly to obtain the relative displacement files. Finally, Option 8 should be executed to obtain the corrected acceleration, velocity, and displacement files. In addition to offering several types of correction procedures for drift, SPADE also allows, if required, nonzero initial conditions to be applied to the velocity and displacement files. The results of Options 6 and 7 are thus only intermediate;

on completion of Option 8 it is intended that the absolute velocities and displacements will have been calculated from the accelerations.

Options 9 to 11 have been included essentially for convenience and do not necessarily have to be executed. Detailed examples are given in Reference 5.

## 8.   CONCLUDING REMARKS

The main purpose of SPADE is to give a facility for performing basic signal processing on the large volumes of data created during blast wave-structure interaction experiments. At the time of writing, the program has successfully been used by five term students to process a considerable amount of data. The students indicated very little difficulty in using the code.

## REFERENCES

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EXPERIMENT
STRUCTURE WITH TRANSDUCERS
AND EDIG INSTRUMENTATION TRAILER

MAGNETIC TAPE FOR
RECORDING OF TRANSDUCER
SIGNALS CALIBRATION
PULSES AND
IRIG SIGNAL

EDIG
DATA SHEET
(EDS)

DIGITIZING
THE COMPUTER GROUP (CG)
CONVERTS ANALOG TRANSDUCER
SIGNALS TO DIGITAL DATA FILES

MAGNETIC TAPE FOR
RECORDING OF DIGITIZED
DATA FILES
CALIBRATION PULSE
DATA FILES (CPDF)
SIGNAL DATA FILES (SDF)

CG
DATA
SHEET
(CDS)

COMPUTER GROUP
TRANSFERS SELECTED
CPDF AND SDF
TO HONEYWELL
DISC FILES

HONEYWELL DISC
CONTAINING SELECTED
CPDF AND SDF

CPDF
SDF

PROGRAM
SPADE

TRANSDUCER DATABASE
FILES (TDF)
TRANSDUCER INFORMATION
FILES (TIF)

SCALED SIGNAL
DATA FILES
(SSDF)

PRESSURE
LOAD FILE
(PLF)

FINITE ELEMENT
CALCULATIONS

FILES PRODUCED
BY FINITE ELEMENT
CODE (FEF)

SDF SSDF CPDF
FEF TIF TDF

PROGRAM
SPADE PLOT

COMPUTER MODELLING
OF EXPERIMENT

HARDCOPY
PLOTS

## Figure 1

## BLOCK DIAGRAM OF THE DATA AQUISITION, PROCESSING,
## PLOTTING, AND ANALYSIS PROCEDURES
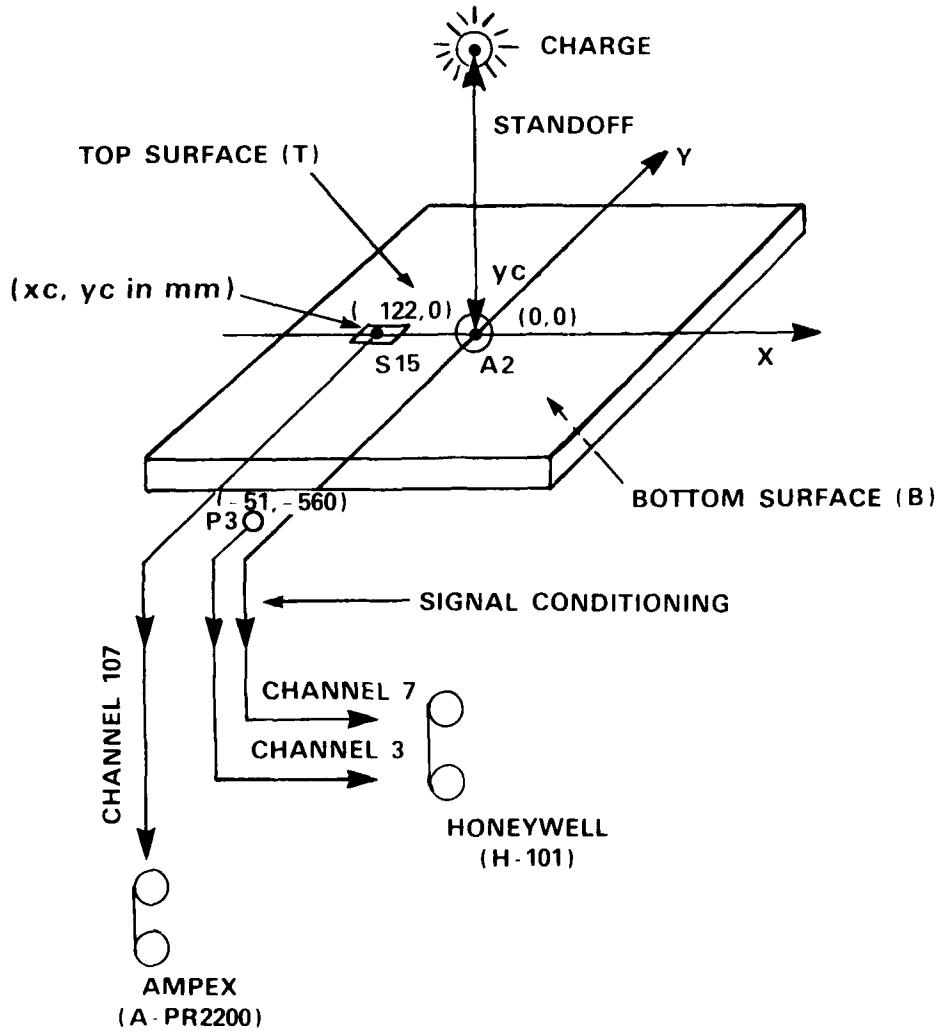
Figure 2

PICTORIAL REPRESENTATION OF A SIMPLE SQUARE PLATE
INSTRUMENTED WITH A PRESSURE GAUGE (P3), A STRAIN
GAUGE (S15, AND AN ACCELEROMETER (A2)
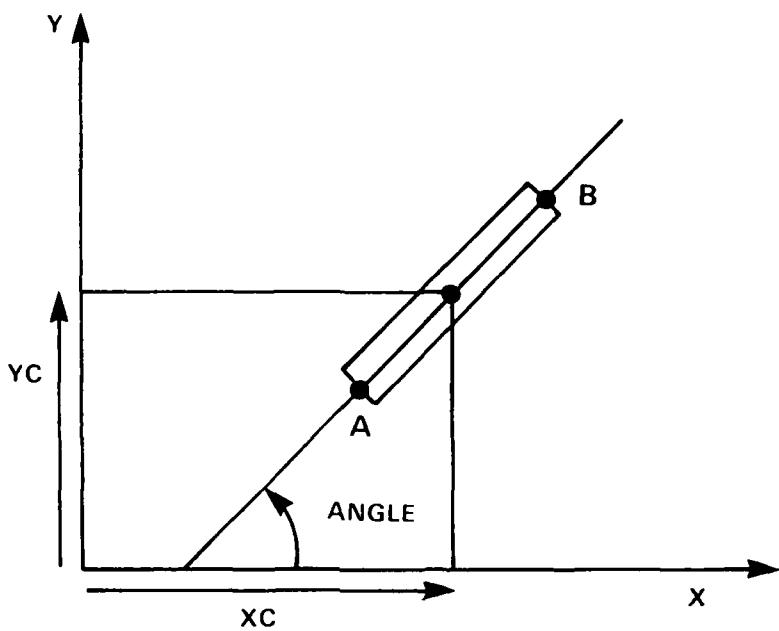
Figure 3

ILLUSTRATION OF THE SPECIFICATION OF COORDINATES
(XC, YC ANGLE) FOR A STRAIN GAUGE

TAPE HEAD

ANALOG SIGNAL

MAGNETIC TAPE

TRACK I
(I = 1 to 12)

$t_2$

$-2000$ ms

V

$-3000$ ms

$t_1$

INCREASING
REAL TIME

VOLTAGE

TRACK 13

DET 0

TRACK 14

$\sim 1000$ ms

TAPE
MOVEMENT

IRIG

DIGITIZING

EDIG DATA
SHEET (EDS)

$\bar{h}(DU) = 204.8 \times GAINXV$

CPDF

$t_1$

TAPE
MOVEMENT

INCREASING REAL TIME

SDF

$t_2$
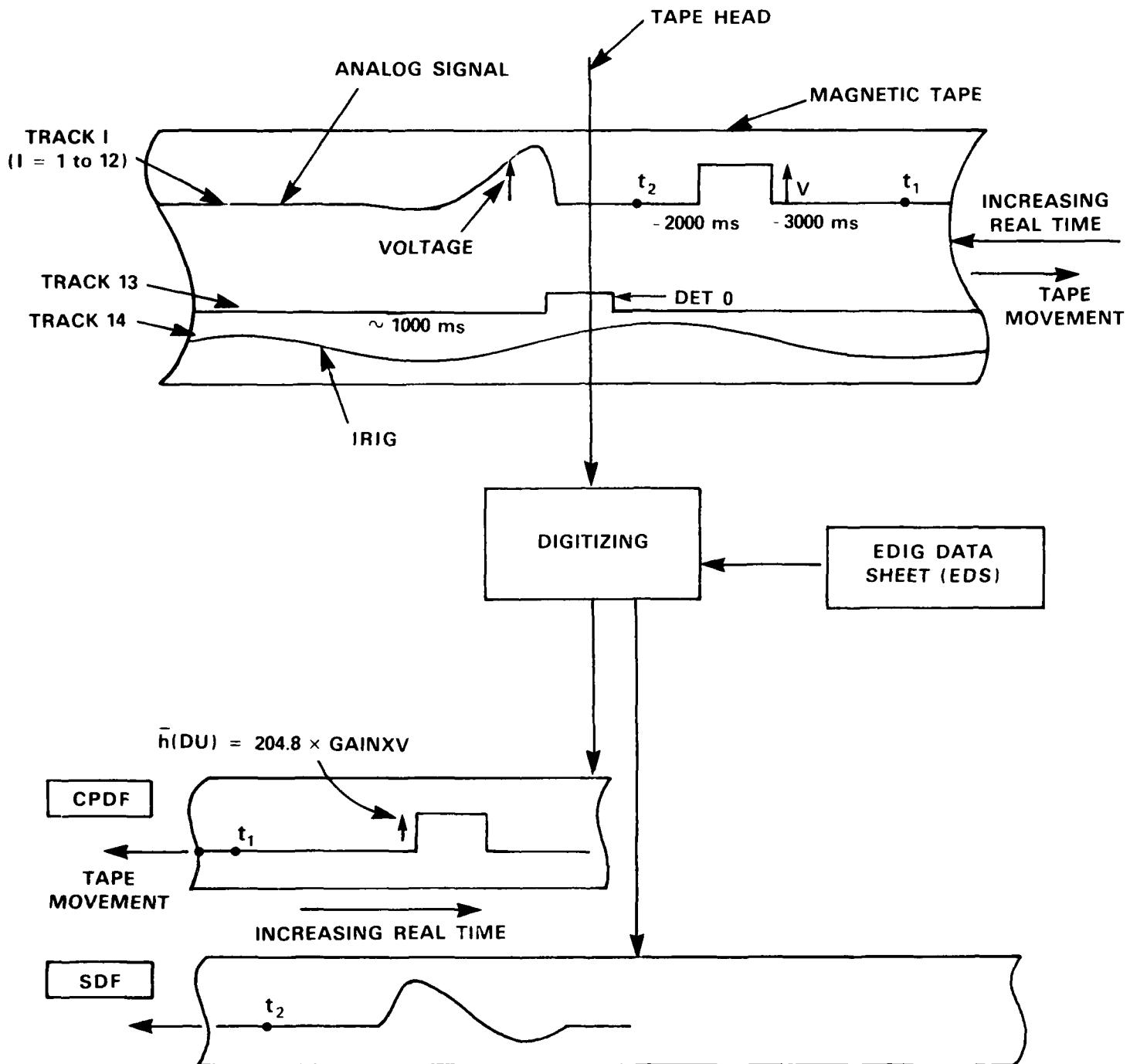
Figure 4

SCHEMATIC ILLUSTRATION OF THE DIGITIZING PROCESS
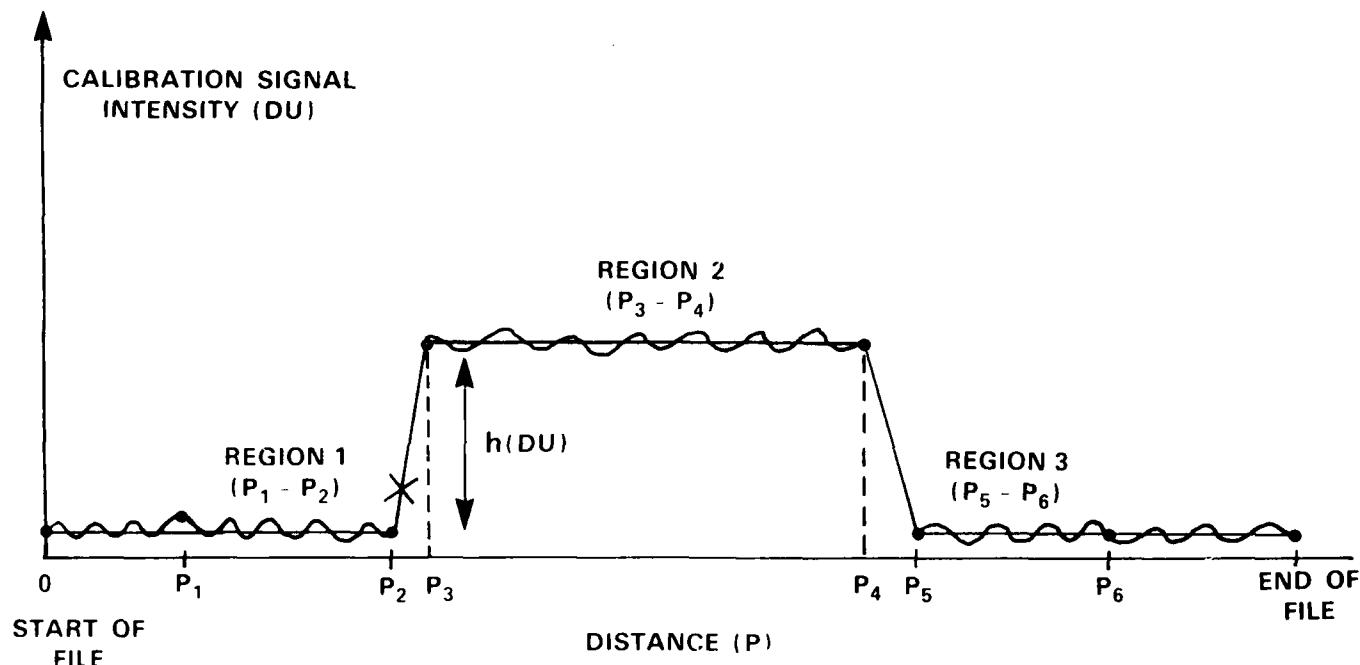
Figure 5

## ILLUSTRATION OF A CALIBRATION PULSE ON A CALIBRATION PULSE DATA FILE WITHOUT BACKGROUND DRIFT
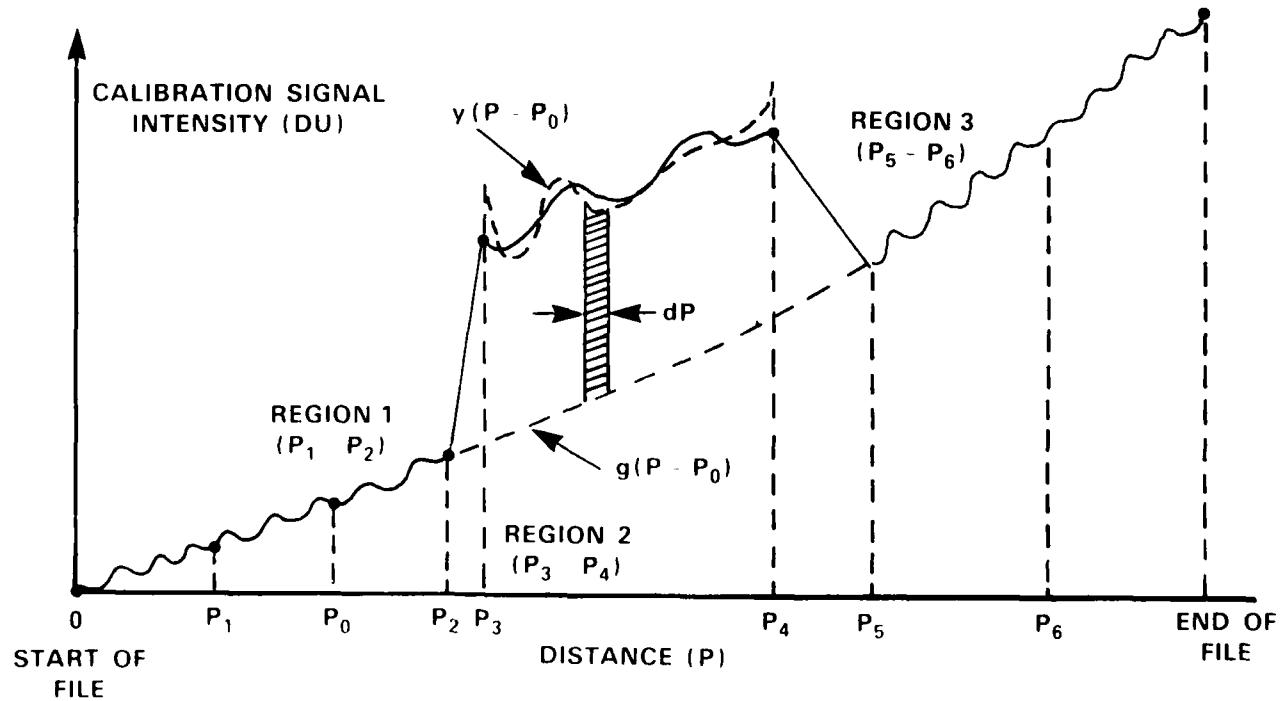


Figure 6

## ILLUSTRATION OF A CALIBRATION PULSE WITH BACKGROUND DRIFT AND NOISE
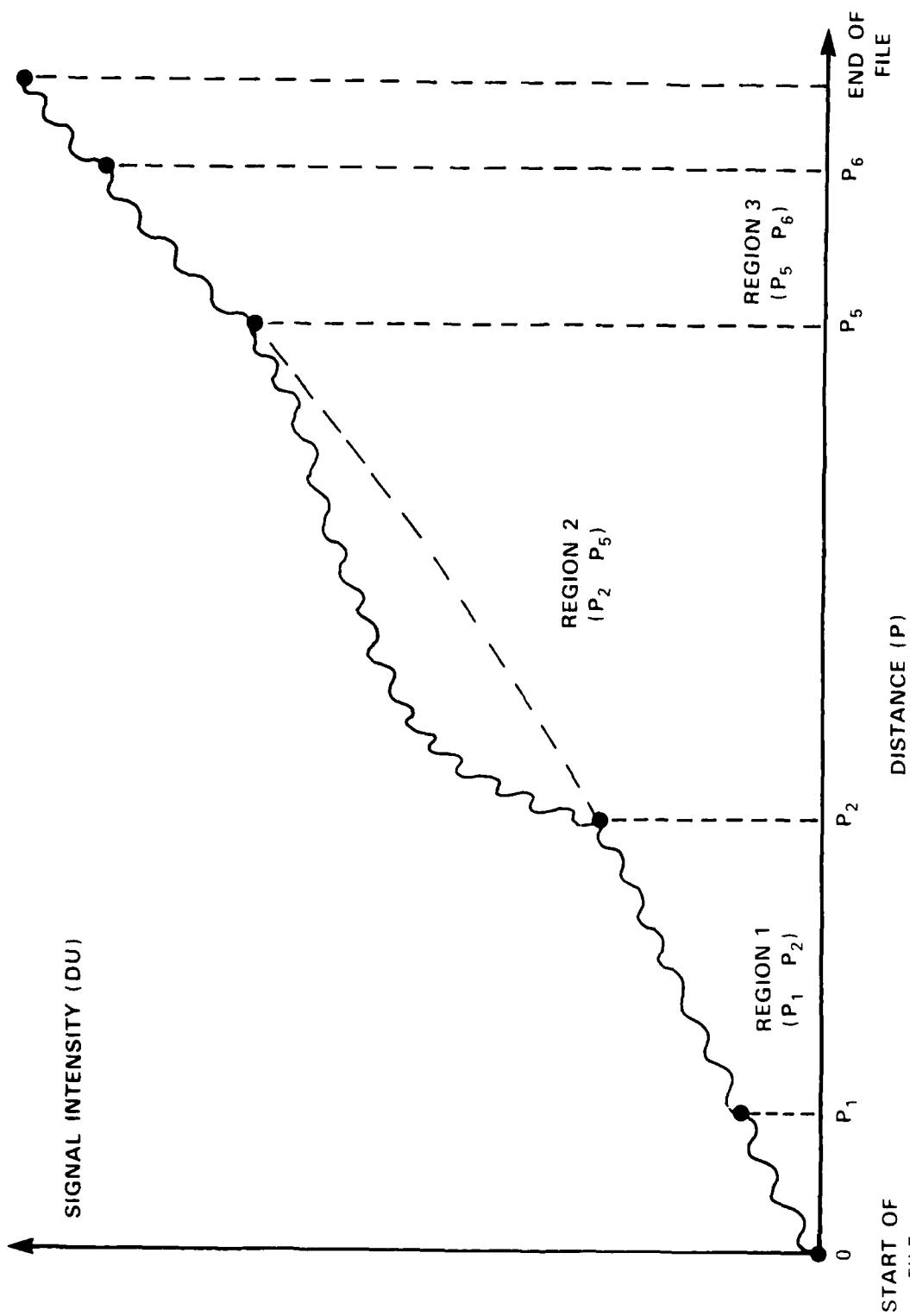
ILLUSTRATION OF A TRANSDUCER SIGNAL STORED ON A
SIGNAL DATA FILE WITH BOTH DRIFT AND NOISE
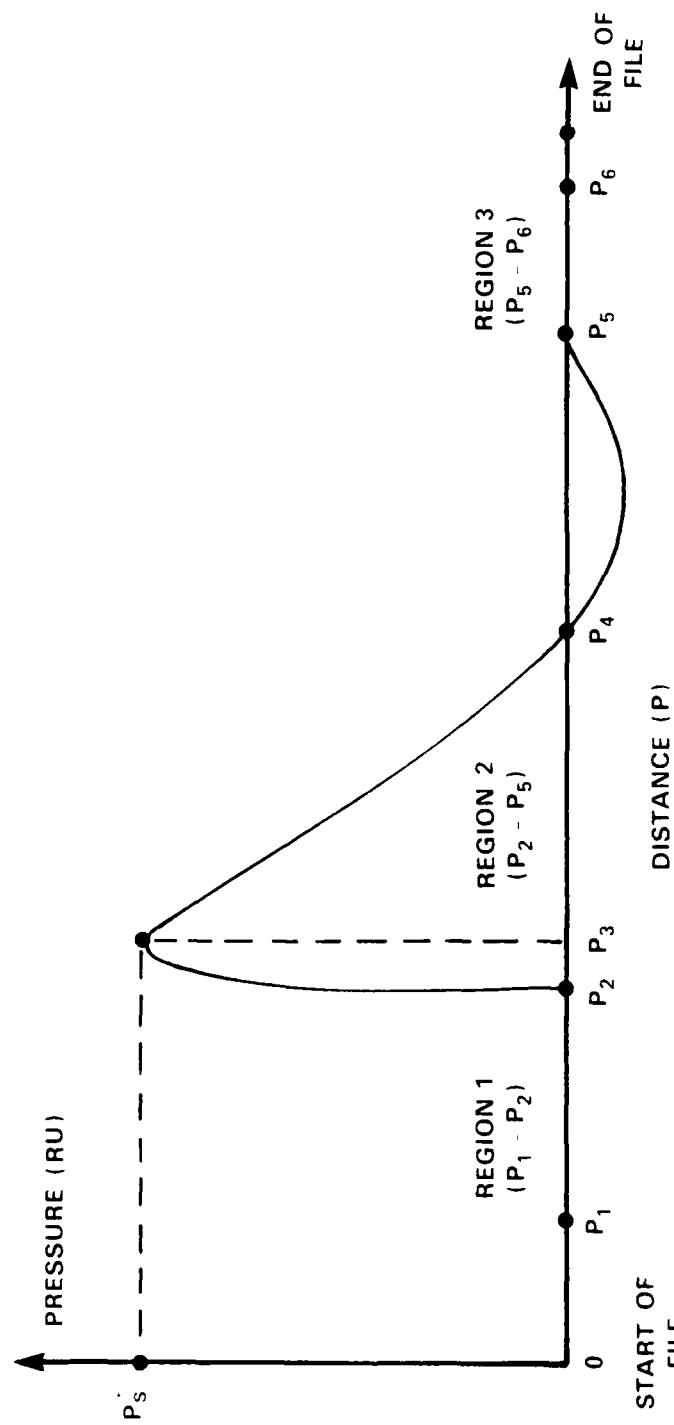
Figure 7

Figure 8

ILLUSTRATION OF THE SIGNAL DEFINITION POINTS FOR A
PRESSURE PULSE ON A SCALED SIGNAL DATA FILE
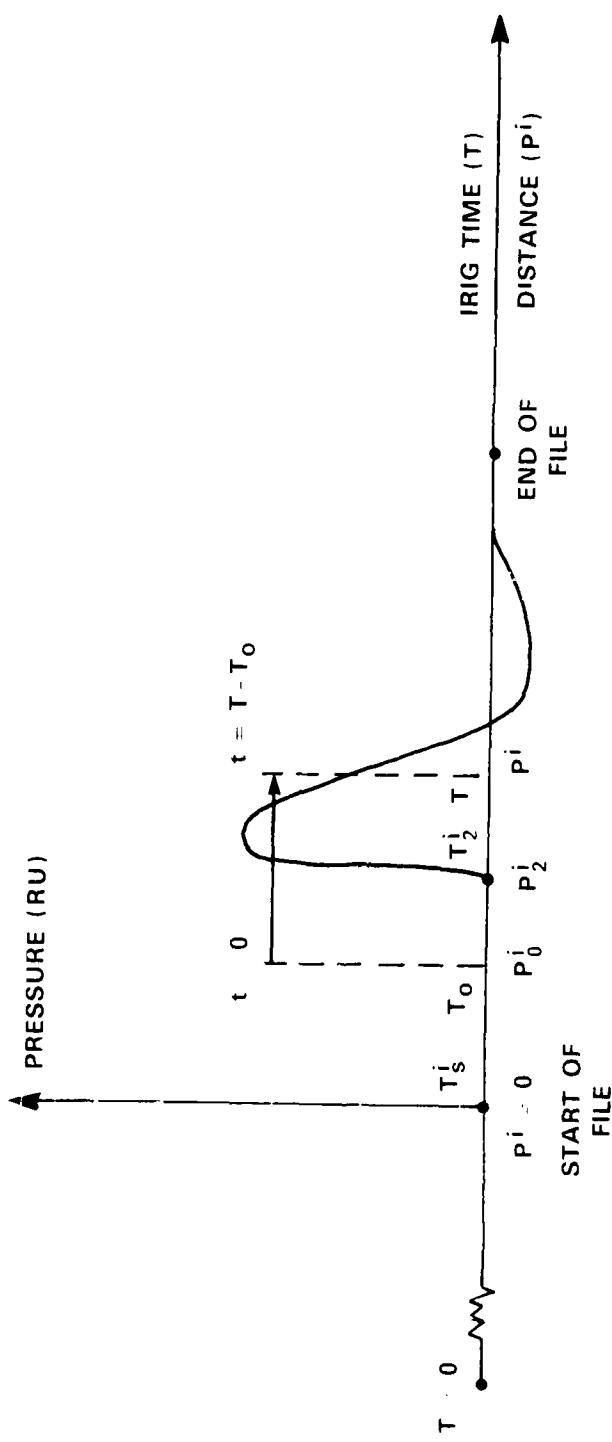
Figure 9

ILLUSTRATION OF QUANTITIES USED FOR THE DETERMINATION
OF THE START TIME ($T_o$) FROM PRESSURE TRANSDUCER SIGNALS

$P(t)$

$P_s^+$

PRESSURE

$d$   $\left(\dfrac{\partial P}{\partial t}\right)_{T_a + T_r}$

$i_s^+$   $\displaystyle\int_{T_a}^{T_a + T^+} P(t)\,dt$

$i_s$   $\displaystyle\int_{T_a + T^+}^{T_a + T^+ + T} P(t)\,dt$

POSITIVE PHASE

$T_a + T^+$

$T_a$   $T_a + T_r$   NEGATIVE PHASE   $T_a + T^+ + T$

$-P_s^-$
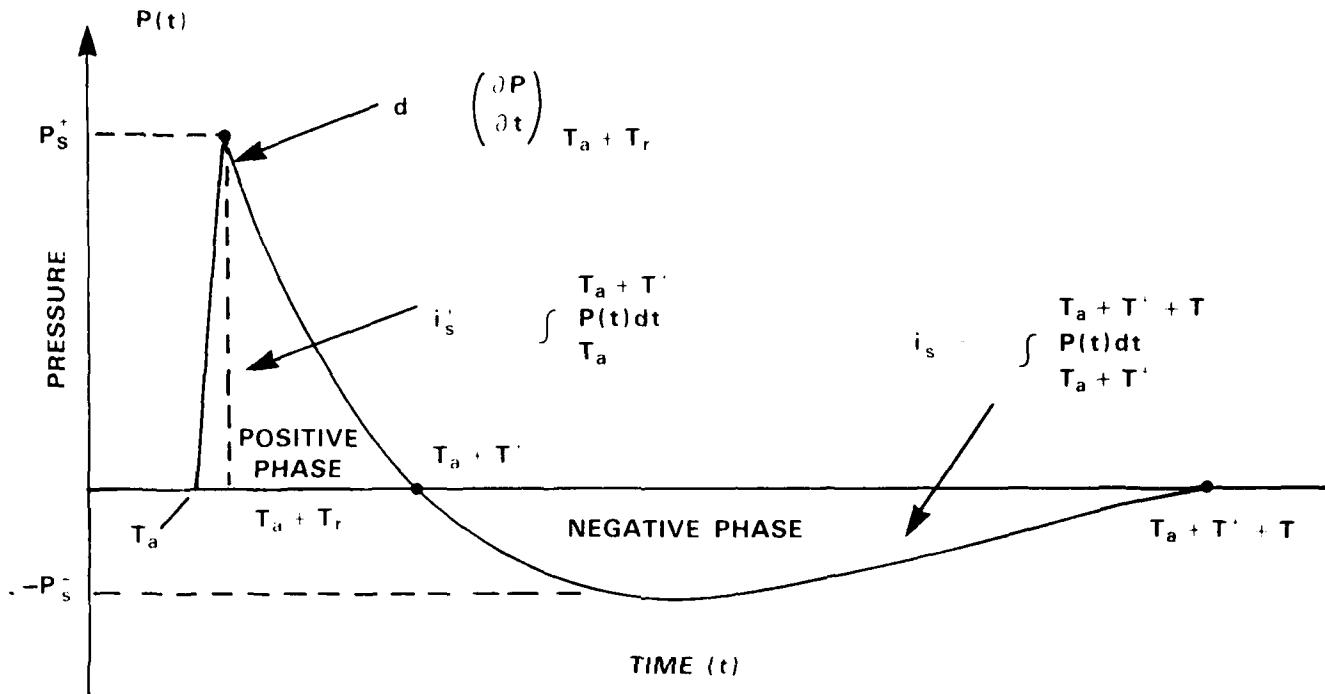
TIME $(t)$

| | | |
|---|---|---|
| $T_a$ | — | ARRIVAL TIME |
| $T_r$ | — | RISE TIME TO PEAK OVERPRESSURE $P_s^+$ |
| $T^+$ | — | POSITIVE PHASE DURATION |
| $P_s^-$ | — | PEAK UNDERPRESSURE |
| $T$ | — | NEGATIVE PHASE DURATION |
| $d$ | — | DECAY RATE |
| $i_s^+$ | — | POSITIVE SPECIFIC IMPULSE |
| $i_s$ | — | NEGATIVE SPECIFIC IMPULSE |

Figure 10

ILLUSTRATION OF PRESSURE PULSE CHARACTERISTICS
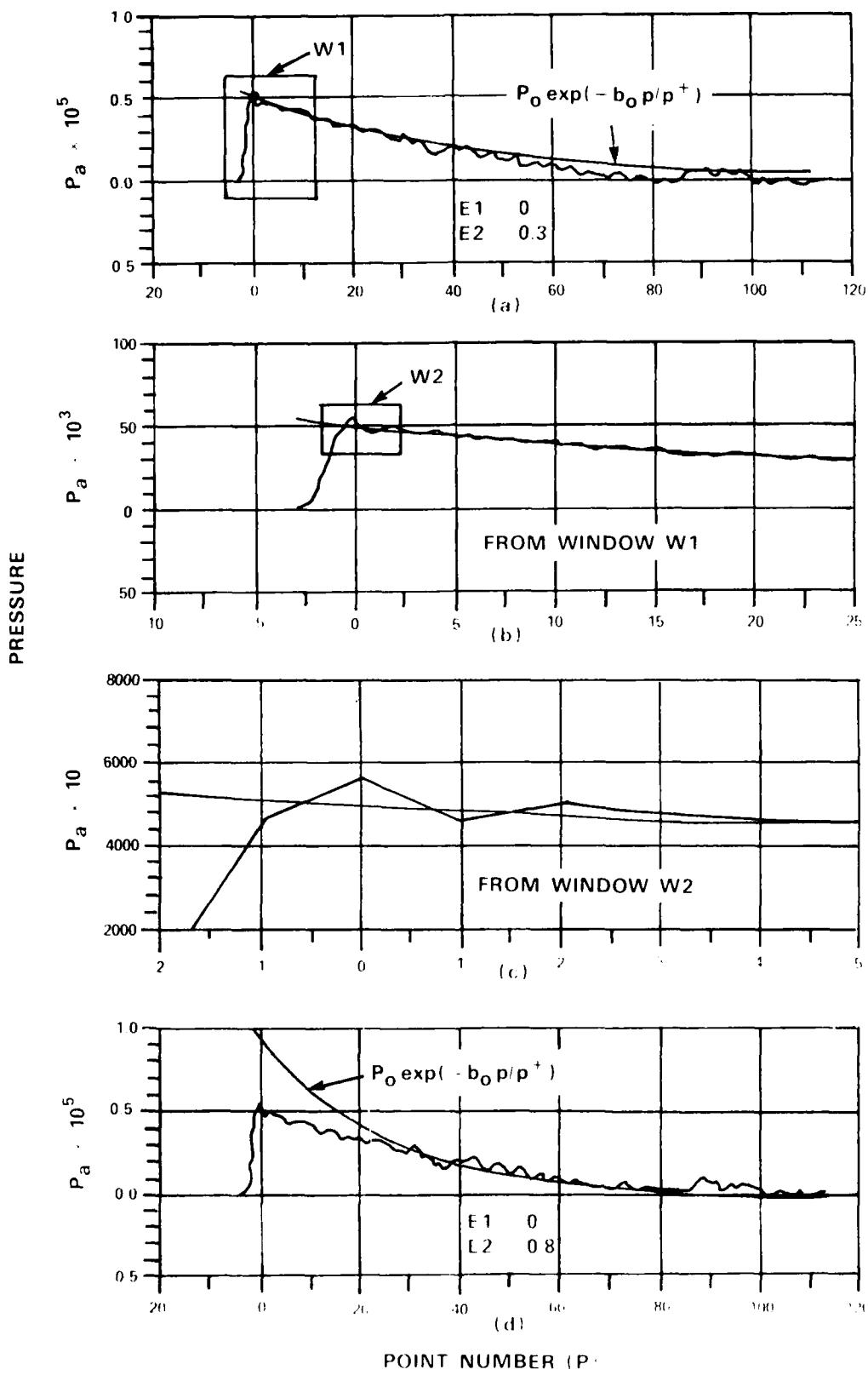
Figure 11

INTERACTIVE GRAPHICS PLOTS DISPLAYING A PRESSURE PULSE
AND CURVE FITS OF THE FORM $P_0 \exp(-b_0 p/p^+)$

- - - PIECEWISE QUADRATIC APPROXIMATION ($\tilde{y}$)
——— REAL FUNCTION (y)

**Figure 12(a)**

$$\tilde{y}_1(t) \quad b_1 + b_2(t-t_1) + b_3(t-t_1)^2$$
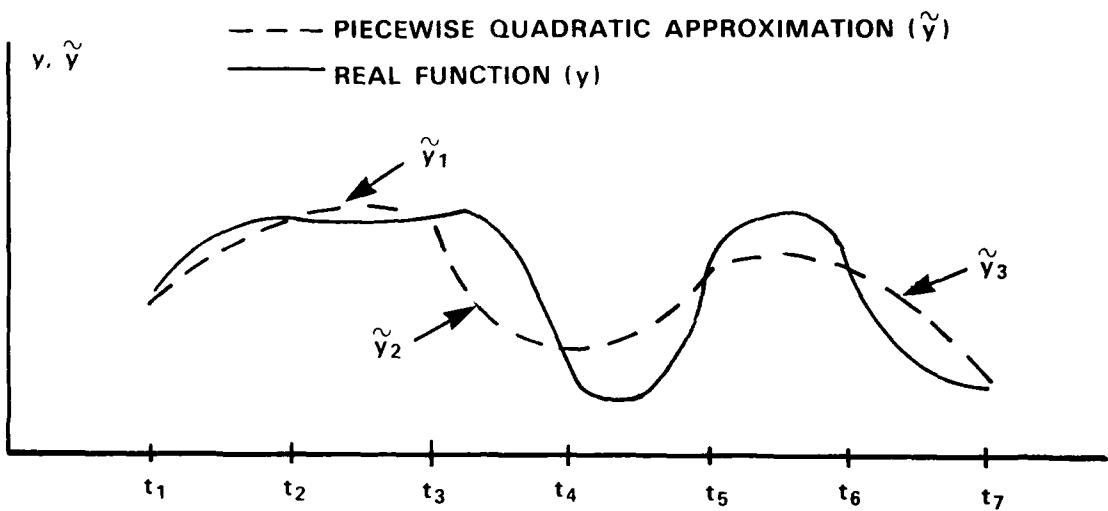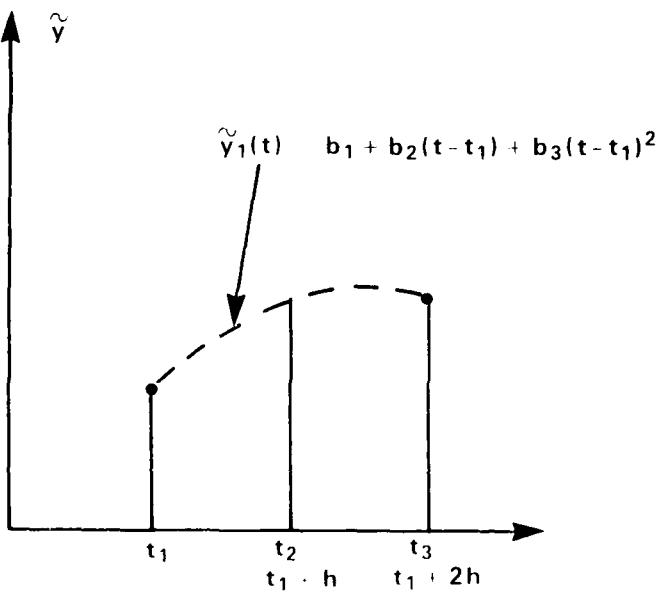
**Figure 12(b)**

## ILLUSTRATION OF THE TYPE OF APPROXIMATE FUNCTION ASSUMED BY SIMPSON'S INTEGRATION RULE
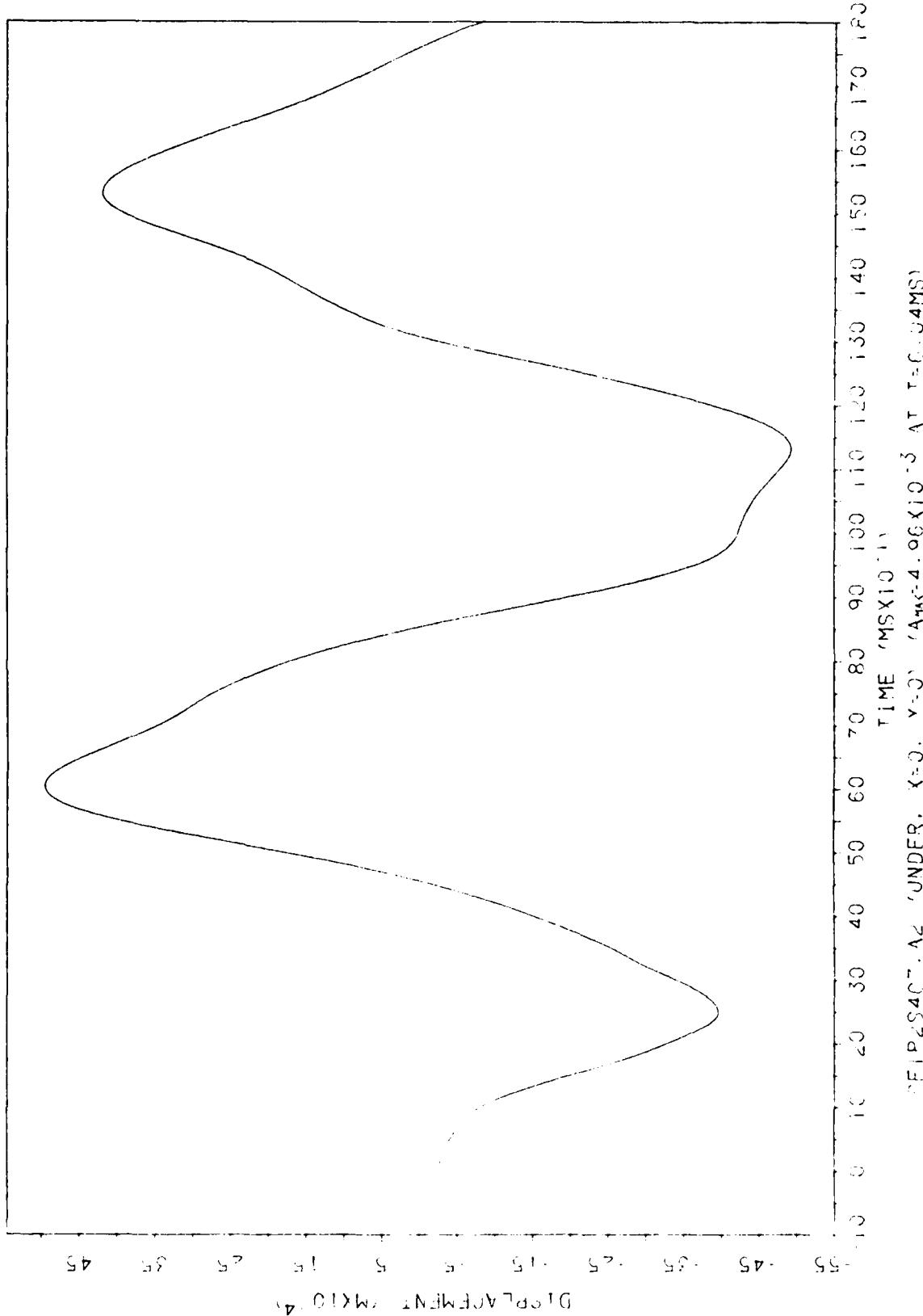
Figure 13

PLOT OF DISPLACEMENT AGAINST TIME FOR THE TRANSDUCER A2
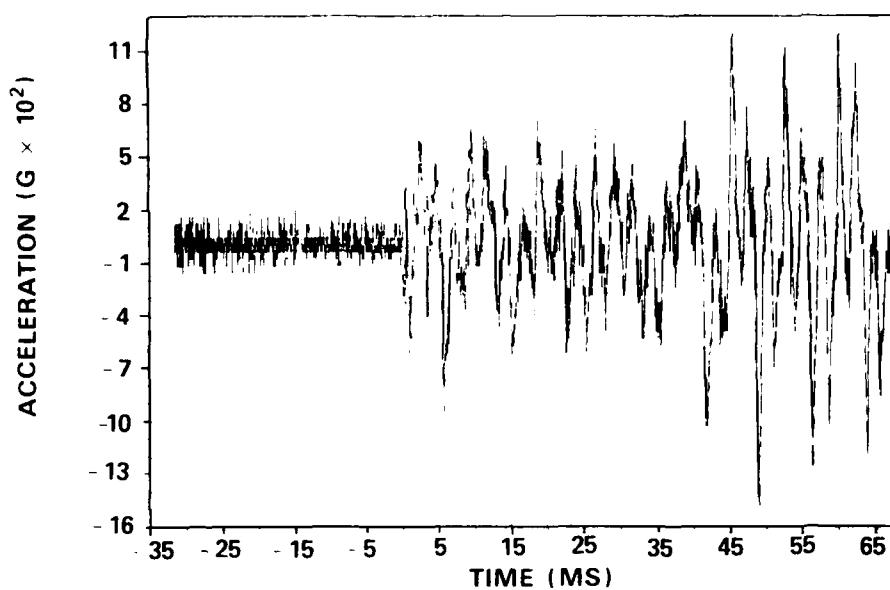
Figure 14(a)

PLOT OF ACCELERATION AGAINST TIME FOR THE TRANSDUCER A 2
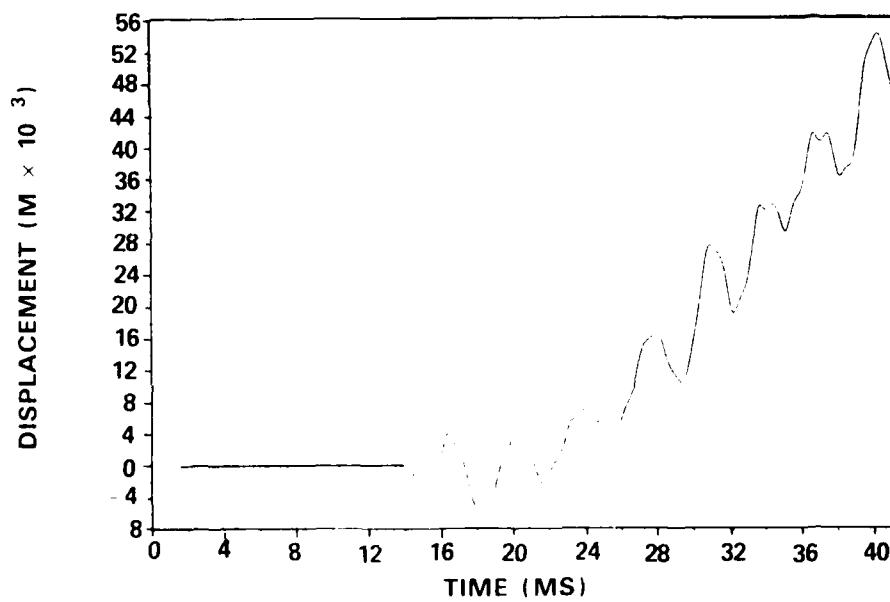


Figure 14(b)

PLOT OF DISPLACEMENT AGAINST TIME FOR THE TRANSDUCER A 2

TYPICAL PLOTS OF ACCELERATION AND DERIVED DISPLACEMENT
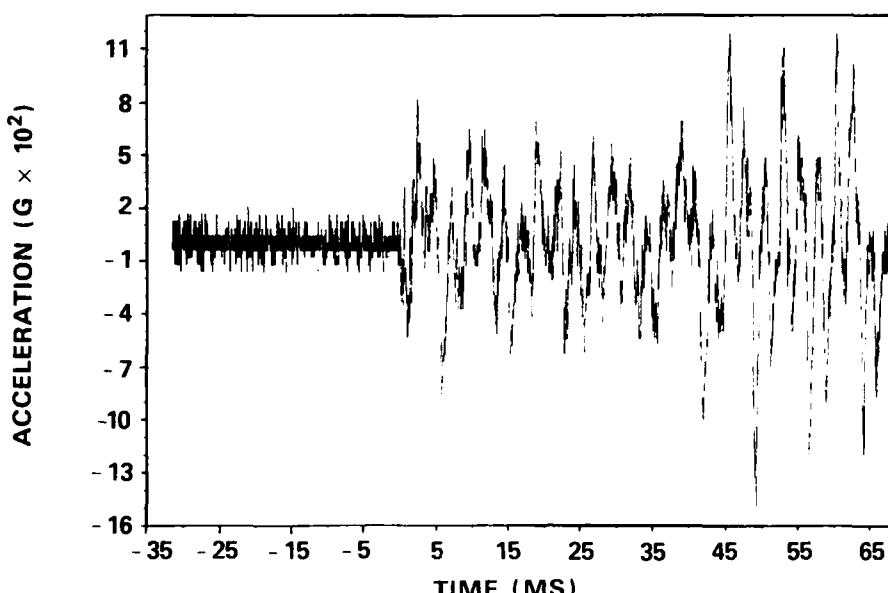
Figure 15(a)

PLOT OF ACCELERATION AGAINST TIME FOR THE TRANSDUCER A 2
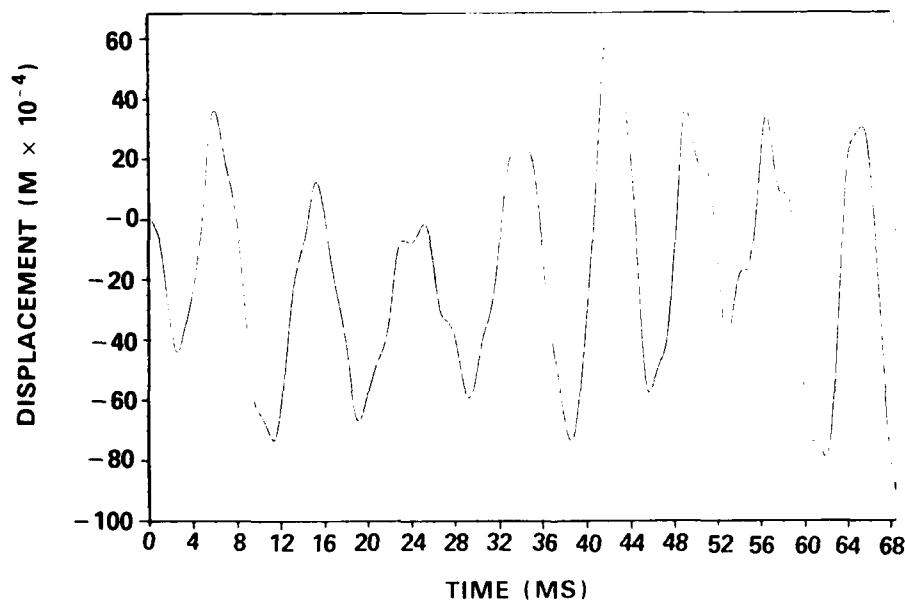


Figure 15(b)

PLOT OF DISPLACEMENT AGAINST TIME FOR THE TRANSDUCER A 2

TYPICAL PLOTS OF CORRECTED ACCELERATION AND
CORRECTED DERIVED DISPLACEMENT

## APPENDIX A

## The EDIG Data Sheet (EDS)

### A1    Introduction

Two sample EDIG data sheets are shown as Tables A1 and A2.  The header
information in each case consists of the following information.  An asterisk
after the name idicates that the quantity is also given on the CDS (Table 5.1).

### A2    Header Information

Charge Size*.  See Section 5.

Height of Burst*.  This is referred to as the Standoff on the CDS.  See
Section 3.1 and Fig. 2.

Tape Number.  This is an identification number for the magnetic tape upon
which the data is recorded.

Date*.  This is the date on which the experiment was conducted.

Shot*.  See Section 3.5.

Ambient Temp.  This is the ambient temperature as reported by the DRES
Meteorology Section.

Ambient Press.  This is the ambient pressure as reported by the DRES
Meteorology Section.

Record Speed.  This indicates the speed in inches per second (ips) for the
magnetic tape when recording tne transducer signals.

.../2

| | | | | | LOCATION | | 7 EST LEVEL | 8 CABLE RF NO | 9 TYPE & S.N | 10 mV in for V out @ GAIN | 11 CALIB R | 12 CALIB ENG.UNITS | 13 OUTPUT UNITS/VOLT | 14 RECORDER TRK & MODE | 15 REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | GRID REF | HORIZTL ANGLE | | | | | | | | | |
| | | | | | | | 10 PSI | 1 | 444 A | 4.0 | | | 10 PSI/V | 1   F.M. | |
| | | | | | 500,551 | | " | 2 | 2 | 3.82 | | | " | 2   F.M. | |
| | | | | | -551,-500 | | " | 3 | 3 | 3.93 | | | " | 3   F.M. | |
| | | | | | -551,551 | | 2 PSI | 4 | 2497A 1 | 9.4 | | | 2 PSI/V | 4   F.M. | |
| | | | | | 551,-551 | | 175 G | 5 | 2497A | 43.5 | 100 KΩ | 215 G | 200 G/V | 5   F.M. | |
| | | | | | 0,0 | | 970 G | 2 | 2 | 12.3 | 50 KΩ | 640 G | 1000 G/V | 6   F.M. | |
| | | | | | 0,0 | | " | 2 | 2 | 12.8 | 50 KΩ | 640 G | 8000 G/V | 7   F.M. | |

REMARKS:

H.O.B. TRIALS          DATA SHEET

Date 31 March/83

Tape No. 1
Record SPD 120 ips
Record LED mR1
Tape Recorder H-20

Shot No. 4

Tape Start 237 ft
Event 346 ft
Tape Shot 474 ft

**TABLE A1**

**EXAMPLE OF AN EDIG DATA SHEET FOR HONEYWELL RECORDER**

RESPONSE OF METAL PLATES TO BLASE WAVE LOADING   H.O.B. TRIALS   DATA SHEET

Shot No. 090 14 10 00   /2.

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

**Header information:**

Charge Size 113 g + DET   Ht. of Burst 10 ft.   Tape No. 1   Date 31 March/83   Shot No. 4

Ambient Temp 17.4° C   Ambient Press _____   Record SPO 120 ips   Tape Start 237 ft   IRIG

Remarks: First Shot on Fully Instrumented   Record STD WB1   Event 348 ft   IRIG

Tape Recorder H-20   Tape Shot 474 ft   IRIG

| | | GAUGE DATA | | LOCATION | | | CABLE | SIGNAL CONDITIONING | | | | | RECORDER | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 3 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| TYPE | S/N | CALIB or G.F. | TOP / BOTTOM | GRID REF | ROSETTE ANGLE | EST LEVEL | RT NO | TYPE & S/N | mV in for/V out or GAIN | CALIB R | CALIB ENG. UNITS | OUTPUT UNITS/VOLT | TRK & MODE | REMARKS |
| A3 | YA17 | 22.5 MΩ .112 MV/G | B | 0,-95 | | 300 G | 3 | 3 | 29.8 | 100 KΩ | 225 G | 300 G/V | 8   F.M. | |
| A4 | YA12 | 20.1 MΩ .121 MV/G | B | 85,-85 | | -100 G | 4 | 4 | 82.5 | 200 KΩ | 104 G | 100 G/V | 9   F.M. | |
| A5 | YA24 | 22.5 MΩ .109 MV/G | B | 0,-169 | | 130 G | 5 | 5 | 45.9 | 100 KΩ | 225 G | 200 G/V | 10   F.M. | |
| A6 | ON9 | 34 MΩ .226 MV/G | B | 169,-169 | | -50 G | 6 | 6 | 263 | 1 MΩ | 34 G | 50 G/V | 11   F.M. | |
| | | 2.1? | | -229,229 | 135° | -80 µε | 7 | 7 | 952 | 500 KΩ | 116 µε | 200 µε/V | 12   F.M. | |
| | | 2.1? | | 126,127 | 135° | 350 µε | 8 | 8 | 476 | 200 KΩ | 288 µε | 400 µε/V | 13   F.M. | |
| | | | | | | | | | | | | | 14   F.M. | |

IRIG B from SATTELITE CLOCK

REMARKS:

**TABLE A1 (Continued)**

**EXAMPLE OF AN EDIG DATA SHEET FOR HONEYWELL RECORDER**

RESPONSE OF METAL PLATES TO BLASE WAVE LOADING

H.O.B. TRIALS  DATA SHEET

Tape No. __1__  Date __31 March/83__  Sheet No. __4__
Record SP0 __60 ips__  Tape Start __1285 ft__
Record STD __WB1__  Event __1359 ft__  090 14 70 05
Tape Recorder __A-16__  Tape Shot __1402 ft__

| CABLE RT NO (8) | TYPE & S/N (9) | SIGNAL CONDITIONING mV in for/V out or GAIN (10) | CALIB R (11) | CALIB ENG. UNITS (12) | OUTPUT UNITS/VOLT (13) | RECORDER TRK & MODE (14) | | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 7 | 359TA 9 | 475 | 200 kΩ | 288 µε | 400 µε/V | 1 | F.M. | |
| 10 | 10 | 1887 | 1 MΩ | 58 µε | 100 µε/V | 2 | F.M. | |
| 11 | 11 | 475 | 200 kΩ | 288 µε | 400 µε/V | 3 | F.M. | |
| 26 | 12 | 476 | 200 kΩ | 288 µε | 400 µε/V | 4 | F.M. | |
| 13 | 13 | 633 | 1 MΩ | 58 µε | 100 µε/V | 5 | F.M. | |
| 14 | 14 | 380 | 100 kΩ | 576 µε | 500 µε/V | 6 | F.M. | |
| 15 | 15 | 952 | 500 kΩ | 116 µε | 200 µε/V | 7 | F.M. | |
| 17 | 17 | 952 | 500 kΩ | 116 µε | 200 µε/V | 8 | F.M. | |

REMARKS:

**TABLE A2**

**EXAMPLE OF AN EDIG DATA SHEET FOR AMPEX RECORDER**

RESPONSE OF METAL PLATES TO BLASE WAVE LOADING     H.O.B. TRIALS     DATA SHEET     Shot No. /2.

Charge Size 114 g + DET  
Ambient Temp 17.4° C  
Remarks

H*. of Burst 10 ft.  
Ambient Press _____  
First Shot on Fully _____  
Instrumented _____

Tape No. 1  
Record SPO 60 ips  
Record STD WB1  
Tape Recorder A-16

Date 31 March/83  
Tape Start 1285 ft  
Event 1359 ft  
Tape Shot 1402 ft

4: IRIG / IRIG / IRIG  
090 14 10 00

| 4 TOP/BOTTOM | 5 LOCATION GRID REF | ROSETTE ANGLE | 7 EST LEVEL | 8 CABLE QT NO | 9 TYPE & S/N | 10 mV in for V out or GAIN | 11 CALIB R | 12 CALIB ENG. UNITS | 13 OUTPUT UNITS/VOLT | 14 RECORDER TRK & MODE | 15 REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -..,136 | 45° | -350µε | 18 | 28 | 476 | 200 KΩ | 228 µε | 400 µε/V | 9  F.M. | |
| | -..,127 | 135° | 400µε | 19 | 19 | 476 | 200 KΩ | 288 µε | 400 µε/V | 10  F.M. | |
| | -..,.. | 90° | 25µε | 20 | 20 | 1887 | 1 MΩ | 58 µε | 100 µε/V | 11  F.M. | |
| | -..,0 | 90° | -450µε | 21 | 21 | 380 | 100 KΩ | 576 µε | 500 µε/V | 12  F.M. | |
| | -.., .. | 90° | 80µε | 22 | 22 | 252 | 500 KΩ | 116 µε | 200 µε/V | 13  F.M. | |
| | | | | | | | | | | 14  F.M. | |

IRIG B from SATTELITE CLOCK

GAUGE DATA

REMARKS

**TABLE A2 (Continued)**

**EXAMPLE OF AN EDIG DATA SHEET FOR AMPEX RECORDER**

Tape Start. This is the number of feet of tape that has been allowed to pass the Tape Head (Fig. 4) prior to starting the tape to record the transducer signals for the experiment. The number of feet is essentially determined by the amount of information already on the tape from earlier experiments. The IRIG B time may also be given for the point at which the tape is started to record the experimental data. This time will be specified in the same format as for the Event (see Section 5).

Remarks. This is for additional information.

Record Std. This is an IRIG standard of recording. WB means "Wide Band". Several different recording standards exist.

Event*. The number of feet of the Tape Head (Fig. 4) from the start of the tape is given for the time when the charge is exploded (Det. Zero). The IRIG B time at Det. Zero is also given (see Section 5).

Tape Recorder. This will indicate either an Ampex or Honeywell recorder as discussed in Section 3.4.

Tape Stop. This is the number of feet of tape that has passed the Tape Head (Fig. 4) when the tape is stopped after the experiment. This amount can then be used to position the Tape Head for a future experiment. The IRIG B time may also be given corresponding to the time at which the tape is stopped.

## A3  Columns on the EDS

### A3.1 Introduction

There are a total of 15 columns on the EDS. Columns 1 to 3 contain gauge data, Columns 4 to 6 contain transducer location information, Columns 7, 8, 14 and 15 contain additional information, and Columns 9 to 13 contain signal conditioning information.

A3.2 Gauge Data (Columns 1 to 3)

Column 1 contains the Transducer Codes as discussed in Section 3.2.

Column 2 contains the Transducer Model and Serial Numbers. Thus P1 has
Model Number 113A21, Serial Number 2686. Also P2 to P4 have the same model
number (113A21) and the indicated Serial Numbers.

Column 3 contains certain gauge constants. These are discussed fully in
Reference 5 along with signal conditioning.

A3.3 Transducer Location Information (Columns 4 to 6)

Columns 4 to 6 contain transducer location data. Column 4 gives the surface
on which the transducer is mounted and is the value listed in Column 6 of the CDS
(Table 5.1). Column 5 contains the Transducer Coordinates (XC, YC) discussed in
Section 3.3 and listed in Columns 3 to 4 of the CDS. For strain gauges only,
Column 6 contains the coordinate ANGLE given in Column 5 of the CDS.

A3.4 Additional Information (Columns 7, 8, 14 and 15)

Column 7 contains just the estimated maximum levels of stimulus to which
each gauge is expected to be subjected. Thus P1 to P3 are expected to be
subjected to pressures of 10 PSI. A2 is expected to be subjected to an
acceleration of 970G. S7 is expected to read a maximum compressive strain of
$80\mu e$, where $\mu e$ denotes microstain. The values in Column 7 are used by EDIG to
set the gain settings for signal conditioning as will be explained in Section
A3.5.

Column 8 contains cable identification numbers used to physically tag each
of the cables attached to transducers. The tags correspond to terminal numbers
which allow EDIG to identify the transducers attached to each cable. It should
be mentioned that these numbers are not the Channel Numbers referred to in
Section 3.4.
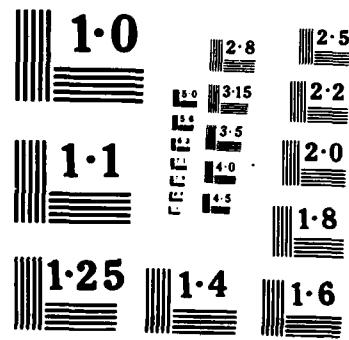
Column 14 contains the track numbers on the magnetic tape used for the transducer signals (see Section 4.2 and Fig. 4). Table A1 for the H-101 tape recorder indicates that the signals from transducers P1 to P4 were stored on tracks 1 to 4, the signals from transducers A1 to A6 were stored on tracks 5 to 11, and the signals from transducers S7 and S8 were stored on tracks 12 and 13, respectively. Track 14 was used to store the IRIG signal. Similarly, Table A2 shows the track numbers assigned to transducers S9 to S22 on the Ampex tape. Note that on both the Honeywell and Ampex tape, track 13 was used to record an actual transducer signal rather than the Det. Zero voltage pulse referred to in Section 4.2. This was done in this case to allow 26 rather than 24 transducer signals to be recorded. All the transducer signals were frequency modulated (F.M.) to reduce the background noise effects.

Column 15 is used to record additional information.

Additional information on the EDIG data sheet can be found in Appendix A of Reference 5.

APPENDIX B

SPADE Data and Database Files

B1    Introduction

Several types of files have been referred to throughout this report.  These are the Transducer Database File (TDF), Transducer List File (TLF), Calibration Pulse Data File (CPDF), Signal Data File (SDF), Scaled Signal Data File (SSDF), Derived Velocity Signal File (DVSF), and Derived Displacement Signal File (DDSF). In the next section, the file naming convention for each will be discussed.  The following sections will then describe the contents and data format.

B2    File Naming Convention

For the purpose of describing the file naming convention the following notation will be used.

Table B2.1
Symbols Used to Describe the File Naming Convention

| Symbol | Meaning |
| --- | --- |
| A-B- | User's prefix. |
| WWW | A Channel Number of up to three digits. |
| XX | A Series Number of up to two digits. |
| YY | A Shot Number of up to two digits. |
| ZZ | A Panel Number of up to two digits. |
| T | A code which is A for acceleration, V for velocity, U for displacement, S for strain, P for pressure, and I for impulse. |
| Cnn | A Transducer Code (see Section 3.2) for a transducer which measures a stimulus of type C, where C is a single character assigned according to the same convention as T.  nn is an integer of up to two digits. |

Table B2.2 below gives the file naming convention for each type of file. The overscored parts refer to the notation described in Table B2.1.

### Table B2.2

### File Name Convention

| File Type | Name |
|-----------|------|
| TLF | A-B-TRANLIST-SEXXSHYY |
| TDF | A-B-TDATA-SEXXSHYY |
| CPDF recorded on H-101 (Section 3.4 and Fig. 2) | H_CCHWWWSHYY_XX |
| CPDF recorded on A-PR2200 (Section 3.4 and Fig. 2) | CCHWWWSHYY_XX |
| SDF recorded on H-101 (Section 3.4 and Fig. 2) | H_CHWWWSHYY_XX |
| SDF recorded on A-PR2200 (Section 3.4 and Fig. 2) | CHWWWSHYY_XX |
| SSDF | A-B-SEXXPZZSYYCnn_T (C and T must designate the same type in this case) |
| DVSF | A-B-SEXXPZZSYYCnn_V (C will denote the type of transducer from which the velocity was derived and will usually be A) |
| DDSF | A-B-SEXXPZZSYYCnn_U (C will denote the type of transducer from which the displacement was derived and will usually be A). |

## B3    Transducer List Files

The TLF are created during the execution of Option 1 in SPADE.  The purpose
of the TLF is to summarize the transducers that are on the TDF and is used for
display purposes only.  The first few lines of the file contain header
information.  After this a listing of the Channel Numbers, Transducer Codes,
Surface Codes, and Transducer Coordinates is given.

## B4    Transducer Database Files

The TDF will contain several lines of data.  The file is formatted and can
thus be altered with the CP6 editor if required.  One of the lines in the file
will contain three asterisks "***" in Columns 1 to 3.  All lines prior to this in
the file will be treated as comment lines by SPADE.  Thus additional comment
lines can be placed in this region with the CP6 editor or otherwise if required.
All lines after the line containing the asterisks are actual data lines.

Each line of data in the TDF contains the quantities listed in the following
table.  The "Terminology" and "Nomenclature" given at the start of this manual
can be referred to for clarification if required.  The "Terminology" also gives
section references.

## Table B4.1.

## Quantities Stored on the TDF

| Quantity | Columns | Quantity | Columns |
|---|---|---|---|
| CHANNEL | 1 - 5 | CPDP $P_6$ | 92 - 95 |
| TRANSDUCER CODE | 7 - 9 | SDP $P_1$ | 97 - 100 |
| CALIBRATE | 11 - 22 | SDP $P_2$ | 102 - 105 |
| SIGNAL SCALE FACTOR | 24 - 35 | SDP $P_3$ | 107 - 110 |
| DRATE | 37 - 48 | SDP $P_4$ | 112 - 115 |
| XC | 50 - 53 | SDP $P_5$ | 117 - 120 |
| YC | 55 - 58 | SDP $P_6$ | 122 - 125 |
| ANGLE | 60 - 63 | $P_0$ (Point Number for t = 0) | 127 - 130 |
| SURFACE | 65 | | |
| CPDP $P_1$ | 67 - 70 | Decay Constant | 132 - 143 |
| CPDP $P_2$ | 72 - 75 | Maximum Impulse | 145 - 156 |
| CPDP $P_3$ | 77 - 80 | Digitizing Start Time | |
| CPDP $P_4$ | 82 - 85 | Y | 157 - 160 |
| | | D | 161 - 163 |
| CPDP $P_5$ | 87 - 90 | H | 164 - 165 |
| | | M | 166 - 167 |
| | | S | 168 - 169 |
| | | MS | 170 - 172 |
| | | MICRSEC | 173 - 175 |
| | | $P_0$ (for curve fit) | 177 - 188 |

In Table B4.1, the Channel, Transducer Code, Calibrate, Drate, XC, YC, Angle, Surface, and Digitizing Start Time are placed in the TDF during the execution of Option 1 as described in Section 6.1. An exception occurs should a CPDF not be available. In this case the Signal Scale Factor is determined in Option 1 on the basis of the Calibration Constant and Gain supplied on the CDS.

The Signal Scale Factor and CPDP (the $P_1$ to $P_6$) are determined in Option 2 except as noted above when a CPDF is not available. The SDP $P_1$, $P_2$, $P_5$ and $P_6$ are determined in Option 3. $P_0$ is determined in Option 4. The Decay Constant and Maximum Impulse are determined in Option 5, as well as SDP $P_3$ and $P_4$.

## B5   CPDF and SDF

The CPDF and SDF contain data samples from the analog tape (see Section 4 and Fig. 4). The format for each line is 10I8. Typically there will be say 5000 samples on the file (and thus 500 lines). As explained in Section 4.3, with a GAIN of 1, a 1 Volt signal on the analog tape will produce the number 204.8 during the digitizing process. This would be stored on the CPDF or SDF as 205 in the format I8.

## B6   SSDF, DVSF and DDSF

The SSDF. DVSF and DDSF are created by SPADE during processing. The format for each line is 10E12.5. In effect, the SDF data stored as 10I8 is replaced by the processed data stored as 10E12.5

## APPENDIX C

## Theory of Least Squares Polynomial Curve Fits

The requirement is to fit a polynomial of the form

$$y = \sum_{I=1}^{m+1} C_I x^{I-1} \tag{C3.1}$$

to a set of N data points $(x_R, y_R)$ where R goes from 1 to N. m is the order of the polynomial and the $C_I$ are the m+1 coefficients. The following condition hold:

| Condition | Consequence |
|---|---|
| 1. m > N-1 | A unique polynomial cannot be fitted to the data points. |
| 2. m = N-1 and no two data points have the same x value. | A unique polynomial can be fitted that will pass through all the data points. |
| 3. m  N-1 | There is no polynomial of order m that will pass through all the data points. |

For condition 3 it is possible to determine a polynomial of order m that will approximate the values of the data points. Using the theory of least squares, this is done by minimizing the sum, S, of the square of the deviations of the polynomial from the data points. S is given by

$$S = \sum_{R=1}^{N} [y_R - \sum_{J=1}^{m+1} C_J x_R^{J-1}]^2 \tag{C3.2}$$

It is then necessary to minimize S by varying the coefficients $C_J$ of the polynomial. The condition for a minimum is

$$\frac{\partial S}{\partial C_I} = 0 \tag{C3.3}$$

for I = 1 to m+1

If Equation C3.2 is substituted into each of the m+1 equations C3.3 there results, for I = 1 to m+1,

$$\frac{\partial S}{\partial C_I} = \sum_{R=1}^{N} \left\{ 2 \left[ y_R - \sum_{J=1}^{m+1} C_J x_R^{J-1} \right] \left[ -\sum_{K=1}^{m+1} \frac{\partial C_K}{\partial C_I} x_R^{K-1} \right] \right\} = 0 \tag{C3.4}$$

On noting the $\partial C_K / \partial C_I = \delta_{KI}$: where $\delta_{KI}$ is the Kronecker Delta ($\delta_{KI} = 1$ if K = I, $\delta_{KI} = 0$ if K $\neq$ I then there results after a straightforward reduction of Equation C3.4

$$\sum_{J=1}^{m+1} A_{IJ} C_J = B_I \tag{C3.5}$$

where

$$A_{IJ} = \sum_{R=1}^{N} x_R^{I+J-2} \tag{C3.6}$$

and

$$B_I = \sum_{R=1}^{N} y_R x_R^{I-1} \tag{C3.7}$$

I can take on values from 1 to m+1 in equations C3.5 to C3.7.  Equation C3.5 can be written in matrix notation as

$$[A][C] = \{B\} \tag{C3.8}$$

where the elements of the matrix $[A]$ are the $A_{IJ}$ given by Equation C3.6.  $\{C\}$

represents a column matrix containing the $m+1$ unknown coefficients $C_I$; namely,

$$\{C\} = \begin{bmatrix} C_1 \\ C_2 \\ \cdot \\ \cdot \\ \cdot \\ C_{m+1} \end{bmatrix} \qquad (C3.9)$$

$\{B\}$ also represents a column matrix containing the $m+1$ values of $B_I$:

$$\{B\} = \begin{bmatrix} B_1 \\ B_2 \\ \cdot \\ \cdot \\ \cdot \\ B_{m+1} \end{bmatrix} \qquad (C3.10)$$

Provided $m+1 \geqslant N$ and not less than $m+1$ of the data points have distinct x coordinates, the system of equations C3.8 can be solved for the unknown coefficients $\{C\}$. In the special case $m+1=N$ (with all the data points having unique x coordinates) the solution of the system of equations will provide the coefficients $\{C\}$ that define the unique polynomial that passes through all the data points according to condition 2 stated above.

The system C3.8 is, in general, badly conditioned but provided $m < 5$ and double precision is used in the calculations the accuracy will normally be adequate. SPADE automatically limits m to the range stated. Values of zero for m are permisible to SPADE also. In this case the single coeffcient $C_1$ will be the average of the $y_I$ values.

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**13 ABSTRACT**

This report describes the theory and operation of a computer program referred to as SPADE (Signal Processing and Data Enhancement).  SPADE is a computer program for the numerical processing of transducer signal data available in the form of digital computer files from air-blast structural response trials.  In addition, the program can graphically compare the processed data with predictions made using the finite element structural analysis computer programs VAST and ADINA.

SPADE is a fully interactive program that can be run from a computer terminal.  The Tektronix TCS PLOT 10 and AG11 packages are used to optionally give an interactive plotting capability.  The program has a reasonably comprehensive set of options which makes it easy and convenient to process the voluminous amount of data that can be generated during a shock wave-structure interaction experiment.  With reasonable ease the program can be adapted to the processing of any type of transducer output.  However, the application of SPADE described in this manual is to the processing of data from pressure transducers, accelerometers, and strain gauges on simple plates and stiffened panels explosed to air-blast shock wave loading.

DSIS
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**KEY WORDS**

Signal Processing, Computer Program, Air-Blast, Structural Response,
Data Analysis

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